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MILITARY HANDBOOK

PIERS AND WHARVES

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PIERS AND WHARVES

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NOTE: THE FOLLOWING REFERENCED DOCUMENTS FORM A PART OF THIS HANDBOOK TO THE EXTENT SPECIFIED HEREIN. USERS OF THIS HANDBOOK SHOULD REFER TO THE LATEST REVISIONS OF CITED DOCUMNETS UNLESS OTHERWISE DIRECTED.

MILITARY HANDBOOKS
Unless otherwise indicated, copies are available from the Standardization Document Order Desk, Building 7D, 700 Robbins Avenue, Philadelphia, PA 191115094.

MIL-HDBK-1002/1	Structural Engineering - General Requirements
MIL-HDBK-1002/2	Loads
MIL-HDBK-1002/3	Steel Structures
MIL-HDBK-1002/5	Timber Structures
MIL-HDBK-1002/6	Aluminum Structures, Masonry Structures, Composite and Other Structural Materials
MIL-HDBK-1005/3	Drainage Systems
MIL-HDBK-1005/7	Water Supply Systems
MIL-HDBK-1005/8	Domestic Waste
MIL-HDBK-1025/2	Dockside Utilities for Ships Service
MIL-HDBK-1025/4	Seawalls, Bulkheads and Quaywalls
MIL-HDBK-1025/6	General Criteria for Waterfront Construction

NAVFAC DESIGN MANUALS AND P-PUBLICATIONS

Available from National Technical Information Service, 5285 Port Royal Road, Springfield VA 22161 Attn: Defense Publications; phone: (703) 487-4684; Fax: (703) 487-4841.

DM-2.04	Concrete Structures
DM-5.04	Pavements
DM-5.06	Trackage
DM-5.10	Solid Waste Disposal
DM-7.01	Soil Mechanics
DM-7.02	Foundations and Earth Structures
DM-7.03	Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction
DM-26.01	Harbors
DM-26.02	Coastal Protection
DM-26.06	Mooring Design Physical and Empirical Data
DM-38.01	Facility Planning Criteria for Navy and Marine Shore Installations
P-401	Pontoon Systems Manual

ENGINEERING AND DESIGN TEXTBOOKS

Information on these documents can be obtained from Commander, Naval Facilities Engineering Command, Code DS02, 200 Stovall Street, Alexandria, VA 22332.

Cargo Handling Facilities (Formerly MIL-HDBK-1025/3) Ferry Terminals and Small Craft Berthing Facilities (Formerly MIL-HDBK-1025/5)

OTHER GOVERNMENT DOCUMENTS AND PUBLICATIONS

Ammunition and Explosives Ashore, NAVSEA OP 5, Vol. 1, Naval Sea Systems Command, Washington, DC 20362

Code of Federal Regulations, CRF 33, Series 1 to 199, General Services Administration, National Archives and Records Service, Office of the Federal Register, Washington, DC 20004

Ice Pressure on Engineering Structures, Bernard Michel, Monogram III-Bib, U.S. Army Cold Regions Research Engineering Laboratory, Hanover, NH 1970

Naval Civil Engineering Laboratory (NCEL) Technical Reports, available from National Technical Information Service, Springfield, VA 22151.

R 605 Reinforced Plastic Landing Float and Brow
TM 5 Advanced Pier Concepts, Users Data Package
TM 51-85-19 Development of Prestressed Concrete Fender Piles - Preliminary Tests
UG-0007 Advanced Pier Concepts, Users Guide

Seismic Design of Piers, Vols. I-III, Tudor/PMB Consulting Engineers, Naval Facilities Engineering Command, Alexandria, VA 22332, August 1976

NON-GOVERNMENT PUBLICATIONS

Dynamic Ice Forces on Piers and Piles, Charles R. Neil, Canadian Journal of Civil Engineering, Vol. 3, Research Journals, National Research Council of Canada, Ottawa, ONT K1A, 1977

Influence Surfaces for Elastic Plates, Adolph Pucher, Springer-Verlag-Wien, 175 Fifth Avenue, New York, NY 10001, 1977

PCI Design Handbook, Prestressed Concrete Institute, 175 West Jackson Blvd, Chicago, IL 60604

Pile Bending During Earthquakes, Edward Margason, Proceedings of Seminar on Design, Construction and Performance of Deep Foundations, College of Engineering, University of California, Berkeley, CA, August 1975

AMERICAN BUREAU OF SHIPPING (ABS)

Rules for Building and Classing Offshore Installations - Part 1 Structures

(Unless otherwise indicated, copies are available from American Bureau of Shipping (ABS), New York, NY 10006.)

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

(AASHTO) Guide Specifications for Bridge Railings

Bridge Guide and Manual Specifications

(Unless otherwise indicated, copies are available from American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Washington, DC 20001.)

Section 1. INTRODUCTION

1.1 Scope. This handbook contains descriptions and design criteria for pier and wharf construction, including subsidiary, contiguous, and auxiliary structures. Loading details, regulations, furnishings, appurtenances, and other information are discussed when applicable.

1.2 Cancellations. This handbook cancels and supersedes ~~NAVFAC DM-25.1, November 1980, and Change 1 dated June 1982.~~MIL-HDBK 1025/1, 30 October 30, 1987 and change 3 dated 30 June 1994.

1.3 Related Criteria. For related criteria refer to the Naval Facilities Engineering Command (NAVFACENGCOM) sources itemized below (see references).

Subject	Source
~~Cargo Handling Facilities~~	~~MIL-HDBK-1025/3~~
~~Civil Engineering – Drainage Systems~~	~~DM-5.03~~
Civil Engineering – Pavements	DM-5.04
~~Civil Engineering – Pollution Control Systems~~	~~DM-5.08~~
Domestic Wastewater Control	MIL-HDBK 1005/8
Civil Engineering - Solid Waste Disposal	DM-5.10
~~Civil Engineering –~~ Trackage	~~DM-5.06~~MIL-HDBK 1005/6
~~Civil Engineering –~~ Water Supply Systems	~~DM-5.07~~MIL-HDBK 1005/7
~~Coastal Protection~~	~~DM-26.02~~
Dockside Utilities for Ship Service	~~DM-25.02~~MIL-HDBK 1025/2
Drydock Facilities	MIL-HDBK 1029/3
Facility Planning Criteria for Navy and Marine Shore Installations	P-80
~~Ferry Terminals and Small Craft Berthing Facilities~~	~~DM-25.05~~
Foundations and Earth Structures	DM-7.02
Graving Drydocks	MIL-HDBK 1029/1
General Criteria for Waterfront Construction	~~DM-25.06~~MIL-HDBK 1025/6
Harbors	DM-26.01
~~Mooring Design Physical and Empirical Data~~	~~DM-26.06~~
~~Pontoon Systems Manual~~	~~P-401~~
~~Seawalls, Bulkheads and Quaywalls~~	~~DM-25.04~~
Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction	~~DM-7.03~~MIL-HDBK 1007/3
Soil Mechanics	DM-7.01
~~Structural Engineering – Aluminum Structures, Masonry Structures, Composite Structures Other Structural Materials~~	~~MIL-HDBK-1002/6~~
~~Structural Engineering - Concrete Structure~~	~~DM-2.04~~
~~Structural Engineering - General Requirements~~	~~DM-2.01~~
~~Structural Engineering – Loads~~	~~DM-2.02~~

Subject	Source
~~Steel Structures~~	~~MIL-HDBK-1002/3~~
~~Timber Structures~~	~~MIL-HDBK-1002/5~~
Weight Handling Equipment	~~DM-38.01~~MIL-HDBK 1038/1

1.4 Definitions

Breasting Dolphin – A freestanding independent structure that a vessel will bear against when current, wind or berthing motion moves the ship into the pier or wharf. Breasting Dolphins are typically equipped with energy absorbing fender systems and are pile supported or solid fill structures.

Bullrail – A wide low curb along the outboard edge of the pier or wharf. The bullrail may be cast-in-place concrete, steel or timber. Bullrails may be fixed or removable. Mooring hardware is often mounted on top of the bullrail.

Camel – A floating structure used to separate a moored vessel from the pier or wharf. Camels are used with ships that have hull configurations that do not match well with typical pier or wharf fender systems, such as, submarines or where vessels require an offset from the pier or wharf due to deck or superstructure overhangs such as an aircraft carrier.

Dolphins – A free standing pile supported or solid filled structure used for mooring and berthing vessels, protection of the end of piers or wharves, turning ships, or protection of bridge substructure.

Drydocks – A specialized facility used for the repair of ships where the vessel is removed from the water or placed within a lock and the water is removed leaving the ship in the dry to facilitate repairs.

Fenders – Energy absorbing devices used on the face of a pier, wharf or dolphin to protect the ship and shore facility from damage due to contact between the two during berthing and mooring.

Monopile Dolphin – A single pile dolphin usually consisting of a large diameter concrete or steel pipe pile filled with concrete. Monopile dolphins can be used as mooring or breasting dolphins. When used as a breasting dolphin, the monopile dolphin is faced with fendering elements.

Mooring Dolphin - A freestanding pile supported or solid filled structure used for mooring vessels. Mooring dolphins are usually placed at the bow or stern of a moored ship to provide mooring points to attach breasting lines, bow lines and stern lines.

Pier - A pier is a structure that projects out from the shore into the water. A pier is oriented either perpendicular to or at an angle with the shore. It may be used on both sides, although there are instances where only one side is used because of site conditions or because there is no need for additional berthing.

Slip – The space between two approximately parallel piers or the space formed by a cut into the land that provides two approximately parallel mooring faces.

Wharf - A wharf is a structure oriented approximately parallel to the shore. Ships can only be moored at the outshore face of a marginal wharf. When water depths close to shore are not adequate to accommodate deep draft ships, the wharf, consisting of a platform on piles, is located offshore in deep water and is connected to shore along its length or at one or more points by pile-supported trestles, usually at right angles to the wharf.

1.5~~1.4~~ General Function. Piers and wharves provide a transfer point for cargo and/or passengers between water carriers and land transport; secure mooring for vessels not under power; facilities for fitting-out, refit or repair; and specialized functions. Where service involves the movement of large volumes of both cargo and passengers, separate facilities should be provided for each. Where one service is subsidiary to another, consideration should be given to the feasibility of accommodating both services at one facility.

1.6~~1.5~~ **Functional Categories ~~Function~~** ~~Classification~~. Piers and wharves are ~~classified according to primary function with the following description~~grouped into four (4) primary types as follows:

1.6.1 **Type I – Fueling, Ammunition, and Supply.**

1.6.1.1 Fueling. These are dedicated piers and wharves equipped with facilities for off-loading fuel from ship to storage and for fueling ships from storage. For additional design criteria, see MIL-HDBK 1025/2, Dockside Utilities for Ship Service

~~1.5.1~~1.6.1.2 Ammunition. These are dedicated piers and wharves used for discharging ammunition for storage and for loading ammunition on outgoing ships. Explosives and ammunition quantity/distance standards are discussed in Naval Sea Systems Command NAVSEA OP 5, Volume 1, Ammunition and Explosives Ashore.

1.6.1.3 Supply. Supply piers and wharves are used primarily for the transfer of cargo between ships and shore facilities. Standard gage railroad tracks may be provided when supplies are expected to be brought in by rail.

1.6.2 **Type II – General Purpose.**

1.6.2.1~~1.5.2~~ Berthing. These are general-purpose piers and wharves used primarily for mooring ships when they are not at sea. Furthermore, berthing facilities may be active, as when ships are berthed for relatively short times and are ready to put to sea on short notice, and inactive as when they are berthed for long periods in a reserve status. Activities that typically take place on berthing piers and wharves are personnel transfer, maintenance, crew training, cargo transfer, light repair work, and waste handling. Under some circumstances, fueling and weapons system testing may also be carried out in these facilities.

1.6.3 **Type III – Repair.**

1.6.3.1 Repair. Repair piers and wharves are constructed and equipped to permit overhaul of ships and portions of a hull above the waterline. These structures are generally equipped with portal cranes or to accommodate heavy mobile cranes.

1.6.3.2~~1.5.3~~ Fitting-Out or Refit. Piers and wharves for fitting-out are very similar to those used for repair purposes, providing approximately the same facilities. However, fitting-out piers and wharves will have, in addition to light and heavy portal cranes, large fixed tower cranes for handling guns, turrets, engines, and heavy armor.

1.6.3.3 Floating Drydocks. Piers and wharves for floating drydocks are constructed and equipped to permit overhaul of ships above and below the waterline. These structures are generally equipped with portal cranes or to accommodate heavy mobile cranes. The dredge depth at these facilities must accommodate the floating drydock when submerged.

~~1.5.4 Fueling. These are dedicated piers and wharves equipped with facilities for off-loading fuel from ship to storage and for fueling ships from storage. For additional design criteria, see MIL-HDBK-1025/3, Cargo Handling Facilities, and Naval Facilities Engineering Command NAVFAC DM-25.02, Dockside Utilities for Ship Service.~~

~~1.5.5 Repair. Repair piers and wharves are constructed and equipped to permit overhaul of ships and portions of a hull above the waterline. These structures are generally equipped with portal cranes.~~
~~1.5.6 Supply. Supply piers and wharves are used primarily for the transfer of cargo between ships and shore facilities. Standard gage railroad tracks may be provided when supplies are expected to be brought in by rail.~~

1.6.4 Type IV – Specialized.

1.6.4.1~~1.5.7~~ Degaussing/Deperming and Electromagnetic Roll. These are piers and wharves specifically used for removing or altering the magnetic characteristics of a ship by means of a powerful, external demagnetizing electrical charge. ~~Further requirements are discussed in Naval Facilities Engineering Command NAVFAC DM-25.05, Ferry Terminals and Small Craft Berthing Facilities.~~

1.6.4.2 **Training, Small Craft, and Specialized Vessels.** These are piers and wharves are typically light structures designed for specific but limited functions. Specific requirements are usually provided by the activity.

1.7~~1.6~~ Flexibility of Berths. Typically, piers and wharves are designed to provide space, utility service, and other supporting facilities for specific incoming or homeported ships. However, berthing plans and classes of ships berthed change with time. While it is not economically feasible to develop a single facility to accommodate and service all classes of ships presently known, the facility should be designed with a certain amount of flexibility built in for anticipated future changes in the functional requirements. This is especially true for berthing piers and wharves which will be used to accommodate different classes of ships as well as support a variety of new operations.

1.8~~1.7~~ Required Features. The following is a list of appurtenances and features generally required for piers and wharves. Dedicated berths may not require all of the listed items, while specialized berths may require additional features.

a) Hotel and ship service utilities
b) Fender systems and separators
c) Mooring devices to safely secure the ship
d) Cranes and crane trackage
e) Access facilities for railroad cars and trucks
f) Waste handling facilities
g) Cargo handling equipment
i) Covered and open storage spaces for cargo
j) Support building, tool shed, office space, and control rooms
k) Lighting poles and equipment
l) Security systems
m) Firefighting equipment
n) Emergency medical facilities
o) Access structures and facilities
p) Fueling facilities
q) Safety Ladders
r) Life-Safety Rings
s) Communications

Section 2. FACILITY PLANNING

2.1 Location and Orientation.

2.1.1 General. The location and alignment of piers and wharves in a harbor should consider factors such as ease of entering and leaving berth, required quayage, harbor line restrictions, foundation conditions, ~~and~~ isolation requirements, prevailing wind and current directions, **clearance to moored or passing vessels, available dredged or dredgable depths,** shoaling patterns, environmental permit restrictions, port **regulations and landside access/proximity**. For discussion and criteria, see Naval Facilities Engineering Command NAVFAC DM-26.01, Harbors.

This document provides minimum facility planning and design criteria for efficient homeport facilities of active surface combatants, amphibious warfare, and combat logistic ships of the following classes: Cruisers (CG 47), Frigates (FFG 7), Destroyers (DD963, DDG 51), Amphibious warfare (LHA 1, LHD 1, LPD 7, LPD 17, LSD 41), Combat logistics (AO 177, TAO 187). AOE, CVN, SSN, MCM, MHC, and MCS are berthed at dedicated facilities. Minimum facility planning and design criteria for efficient homeport operations of active Nimitz class aircraft carriers is also included herein. Existing ports, facilities, and berths may not meet all criteria and may therefore, perform less efficiently, but do not necessarily require upgrade.

Piers and wharves at homeporting facilities may be grouped into 4 standard service categories

1.2 Type I – Fueling and Ammunition

Type II – General Purpose

Type III - Repair

Type IV - Specialized

The requirements are different for each type. This document focuses on the entire homeport operation. The ship will visit fueling and ammunition piers for short periods, but generally berth at general purpose berthing piers. All ships will undergo a Phase Maintenance Program and based on the Class Maintenance Plan (CMP) it may be at a repair berth. Ships in dry dock, at liberty ports, and in inactive status require specialized criteria that NAVFAC will provide as requested. Every 18 months the carrier will undergo a 6-month “Planned Incremental Availability (PIA)” at the repair berth.

2.1.2 Coordination of Repair. Coordinate capability of local ship repair facilities and salvage operations with NAVSEASYSCOM SUPSHIP, COMNAVSURFLANT N4, or COMNAVSURFPAC N4. For CVN’s coordinate with

NAVSEASYSCOM PMS 312 and Code 08, COMNAVAIRLANT N4, or COMNAVAIRPAC N4. The following facilities should be available within a reasonable distance from the support facility homeport to minimize disruption to families and to allow an acceptable level of sailor quality of life as defined in PERSTEMPO requirements (OPNAVINST 3000.13A).

a. A Ship Maintenance Facility (SMF) housing the machine tools, industrial processes and work functions necessary to perform non-radiological depot level maintenance on ship propulsion plants.

b. A Maintenance Support Facility (MSF) housing both administrative and technical staff offices supporting ship propulsion plant maintenance, as well as central area for receiving, inspecting, shipping, and storing hazardous/mixed waste materials and maintenance materials, and controlled radiological tank storage.

c. A Controlled Industrial Facility (CIF) or Radiological Work Facility used for the inspection, modification, and repair of radiological controlled equipment and components associated with Naval nuclear propulsion plants. It also provides facilities and equipment for the treatment, reclamation, and packaging for disposal of radiologically controlled liquids and solids. It includes non-radiologically controlled spaces for administration and other support functions.

d. Dry-dock facilities for CVN’s exist only in the Hampton Roads area. Aircraft carriers will be located at these facilities to this location during periods when this service is required. Facilities for other ships exist at the following locations: Norfolk Naval Shipyard, Puget Sound Naval Shipyard, Pearl Harbor Naval Shipyard, and Sasebo Bay. Consult with NAVSEA and the ship’s Maintenance Program Master Plan and Class Master Plan (CMP) for specific requirements.

e. Phased Maintenance Activities (PMA). PMA is a short, labor intensive availability for ships in a Phased Maintenance Program for the accomplishment of maintenance and modernization. At some Naval stations, PMA performed at berthing piers will be of significant magnitude. Requirements for space and pier dimensions due to PMA should be considered for these facilities. The four levels of PMA and their estimated space requirements are as follows:

- Intermediate Maintenance Availability (IMA). IMA consists of removal and repair of shipboard equipment performed by Shore Intermediate Maintenance Activity (SIMA) personnel or tender forces, with a duration of approximately 30 days. Gross deck requirements range from 2000 to 3000 ft^2 (186-279m^2) with work area dimensions varying from 30 x 65 ft (9.1 x 19.8 m) to 30 x 100 ft (9.1 x 30.4 m).

- Planned Restricted Availability (PRA). PRA consists of limited repairs of shipboard equipment and systems by contract forces under Supervisor of Shipbuilding and Repairs (SUPSHIP) control, with a duration of 30 to

60 days. Gross deck area requirements are about 10,800-ft^2 (1003 m^2) at 35 x 310ft (10.7 x 95 m) of command and storage area could be on the lower level.

- Selected Restricted Availability (SRA). SRA consists of expanded repairs and/or minor ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of approximately 60 days. Gross deck area requirements are about 18,000 ft^2 (1672 m^2 at 35 x 515-ft (10.7 x 157 m). On a double-deck pier with adequate clearance, about 5000 ft^2 (464 m^2) of command and operational area could be on the lower level.

- Regular Overhaul (ROH). ROH consists of major repairs and ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of six to eight months. Gross deck area requirements are about 23,000-ft^2 (2136 m^2) at 35 x 660-ft (10.7 x 201 m). In addition, there would be a requirement for turnaround areas on deck and warehousing off the pier or wharf. On a double-deck pier, up to 8000 ft^2 (743 m^2) of command and operational area could be on the lower level.

2.1.~~2~~3 ~~Wind and Currents~~ Orientation for Environmental Conditions. To the extent practicable, piers and wharves should be oriented so that a moored ship is headed into the direction of the prevailing winds and currents. Thus, the forces induced on mooring lines by these conditions would be kept to a minimum. If such an arrangement is not feasible, an orientation in which the wind or current holds the ship off the facility should be considered, although the difficulty in mooring a ship under such conditions should not be overlooked. In locations where criteria for both wind or current cannot be met, the berth should be oriented parallel to the direction of the more severe condition. At locations exposed to waves and swell, the facility should be located so that a moored ship is headed into the wave or swell front. If planning criteria dictate that a pier or wharf be oriented so that a moored ship is positioned broadside to the prevailing winds, currents, or waves, breast-off buoys should be considered to keep the ship off the facility and diminish the possibility of damage to the structure and ship. At oil storage terminals located in areas where meteorological and hydrological conditions are severe, consideration should be given to the utilization of a single point mooring which allows a moored tanker to swing freely when acted upon by winds, waves, and currents from varying directions. See MIL-HDBK 1026/4 for additional information relating to the design of moorings and fenders.

2.1.~~3~~4 ~~Turning Basin~~ Vessel Ingress and Egress.
On occasion, a moored vessel is required to make a hasty departure from its berth and head out to sea. Accordingly, when planning a pier or wharf, consideration should be given to providing adequate turning area so that a ship can be turned before it is docked, and moored with a heading that will permit a convenient and rapid departure.

2.1.4.1 Disaster Control and Emergency Plans.

a. In an emergency, tugs may not be available. Therefore, the slip, berth, basin, and channels should allow the ship to get underway without assistance. See OPNAVINST 3040.5c.

b. Should the ship be unable to leave prior to heavy weather (such as during a PMA (or PIA for CVN)), a Heavy Weather Mooring plan should be established for winds from 34 knots (39 mph) to the predicted 100-year recurrence wind speed at the site. General-purpose berths are normally designed for 64-knot (75-mph) winds. Therefore, winds in excess of 64 knots (75 mph) such as may be seen at repair berths require special considerations. See the heavy weather mooring criteria in Naval Facilities Engineering Service Center (NFESC) Technical Report (TR) 6012-OCN, “U.S. Navy Heavy Weather Mooring Criteria”.

c. Design facility systems for continuous operation in the event of a power outage.

2.1.4.2 Channel Approaches. (Outer Channels) – site specific criteria

a Coordinate dimensions of approaches with the NAVFAC Criteria Office, NAVSEASYSCOM, and COMNAVSURFLANT N4, or COMNAVSURFPAC N4. Consideration should be given to traffic lanes, local commercial traffic, navigational aids, magnetic anomalies, electronic navigation aids, waves, winds, currents, use-frequency, pilotage and tugs. Contact the US Coast Guard for navigational marking requirements and bridge clearances.

b. The geometrics of the approaches (depth, width, and course) are dependent on many operational and environmental factors. The wave environment greatly affects the required depth to transit the approach. Local commercial traffic affects the width. Maneuverability is the primary driver for the course. Consequently, the planner must examine each channel approach separately. Contact the NAVFAC Criteria Office to assist in evaluating or designing channel approaches.

c. Contact the local NAVFAC representative, who will contact the US Army Corps of Engineers to address environmental and material disposal issues. Generally, this effort will be part of NEPA compliance.

2.1.4.3 **Entrances.** (Inner Channels) and Harbors – site specific criteria

a. Entrance Restrictions – Entrance channels provide access between deep water subjected to a strong wave environment to sheltered harbors. Contact local Port Authority for any operational restrictions.

b. Entrance Currents - Strong currents greatly affect the usability of entrance channels. These currents should be quantified and the impact assessed during the planning stages.

c. Minimum Entrance Depth - Different ships require differing amounts of water during transit of channels (usually during mean to high tides) greater than 1000 ft. (305m) wide. CVN’s require 50 ft. Narrower channels require greater depths. Tides and waves should be quantified and the impact assessed to determine if a greater dredge depth is required. Siltation occurs in most channels and shall be quantified initially. The design depth should then be deeper than the requirement to accommodate siltation. Expected siltation can be addressed through advance maintenance dredging or other means. Determine whether the proposed depth is great enough to avoid interference with the vessel's hull and special electronic apparatus that might be attached. Entrance depth is also dependent on draft, trim, list, salinity, and clearance requirements. See NAVSEA ltr 11460 Ser 03D3/242, dated 3 Jan 95, "CVN 68 Class Water Depth Requirements".

d. Minimum Entrance Channel Width (outside breakwaters) – depends on ship speed, wave, wind, and current environment but generally at least 500 ft. (152.4m) for surface combatants, 700 ft. (213.4m) for amphibious, and combat logistic ships, and 800 ft for CVN's, at toe of slope, assuming no bends in the channel and one way traffic during transit.

e. Vertical Bridge Clearances - 180-ft. (55m) above Mean Higher High Water (MHHW) when ship is in light condition. Light condition occurs when the ship is intact in every respect with water in the boilers at steaming level and liquids in machinery and piping but with empty tanks and bunkers, no passengers, minimal crew, cargo or provisions. CV and CVN have no aircraft, airwing, ammunition, and has 55% of JP-5, 10% of provisions and stores, 10% of potable water, aircraft handling vehicles, and 25% onboard discharge tank water, is intact in every respect with water in the boilers at steaming level and liquids in machinery and piping but with empty tanks and bunkers and no passengers, minimal crew, cargo or provisions. For the older CV's, a height of 250 ft. MHHW is required. If the facility is designed explicitly for Nimitz class, use 230 ft. MHHW.

f. Turning Basin Criteria –For surface combatants, 1700 ft (518m) (optimal)/ 1275 ft (389m)(absolute minimum with full tug support) radius {diameter?}. Tug availability should be considered. Minimum depth = 36 ft (11m)(w/o T-AO) at Mean Lower Low Water (MLLW) and 45 ft {Is 45 ft correct?}(13.7m)(w/T-AO) at Extreme Low Water (ELW) with no waves. For CVN's, provide radius {diameter?} of 2200 ft. optimal/1650 ft. absolute minimum with full tug support. Minimum depth required is 49.5 ft. at Mean Lower Low Water (MLLW) and 45.5 ft. at Extreme Low Water (ELW) with no waves.

g. Minimum Inner Channel Width (inside breakwaters) – is generally at least 400 ft. (122m) for surface combatants, and 600 ft. (183m) for amphibious and combat logistic ships, and CVN's at toe of slope, assuming no bends in the channel and no other traffic during transit. Narrower widths may create maneuverability difficulties, increase risk of grounding, and increase sinkage thus reducing efficient homeport operations.

2.1.~~4~~5 Pier Orientation.
A pier is a structure ~~which~~ that projects out from the shore into the water. A pier is oriented either perpendicular to or at an angle with the shore. It may be used on both sides, although there are instances where only one side is used because of site conditions or because there is no need for additional berthing. Piers may he more desirable than wharves when there is limited space available because both sides of a pier may be used for berthing and mooring ships. The space between two approximately parallel piers or a pier and a wharf ~~is usually~~ may be referred to as ~~the~~ a slip.

2.1.~~5~~6 Wharf Orientation.
A wharf is a structure oriented approximately parallel to the shore. ~~When the wharf is connected to the shore along the full length and a retaining structure is used to contain upland fill placed behind the wharf, it is call a marginal wharf.~~ Ships can only be moored at the outshore face of a ~~marginal~~ wharf. When water depths close to shore are not adequate to accommodate deep draft ships, the wharf, consisting of a platform on piles, is located offshore in deep water and is connected to shore at one or more points by pile-supported trestles, usually at right angles to the wharf. If the trestle is located at the center of the wharf, the structure is referred to as a T-type wharf; if the trestle is located at an end, the facility is known as an L-type wharf; if trestles are located at both ends, the wharf is called a U-type wharf. Ships may be berthed on both sides of a T- or L-wharf. When the offshore wharf is used for transfer of bulk liquid cargo from the unloading platform to shore via submarine pipelines, the structure is referred to as an island wharf. A trestle from the offshore wharf to shore is not provided and both sides of the island wharf may be used for mooring ships. Launches are used for wharf access. Where a U-shaped berth is formed by a cut into land by two approximately parallel wharves, this may be referred to as a slip. For examples of pier and wharf types, see Figures 1 and 2. For general cargo, supply, and container terminals, a wharf structure, connected to upland shore area for its full length, is preferred because such an arrangement is more adaptable to loop rail and highway connections and the distance from wharf apron to transit sheds and open storage areas is shorter.

2.1.~~6~~7 Water Depth.
At locations where the required depth of water is available close to shore and the harbor bottom slopes steeply out to deeper water, it may not be economical to build deep water foundations for a pier, and a wharf structure should be considered. At locations where water depths are shallow and extensive dredging would be required to provide the required depth of water close to shore, consideration should be given to locating the facility outshore, in deeper water, by utilizing a T-, L-, or U-type wharf.

2.1.~~7~~8 Dolphins.
These are small independent platforms or groups of piles used by themselves or in conjunction with a pier or wharf for specialized

purposes. A mooring dolphin is sometimes used at the outboard end of a pier and either or both ends of a wharf to tie up the bow or stern line of a ship at a more favorable angle. Mooring dolphins are usually accessed by a catwalk, as illustrated in Figure 1, and are provided with a bollard or capstan. Breasting dolphins are sometimes used for roll-on/roll-off facilities and at fueling terminals where a full-length pier or wharf is not required. They may also be used as part of the fender system. A turning dolphin is an isolated structure used solely for guiding the ships into a berth or away from known obstructions. Occasionally, a mooring dolphin may also be designed to function as a turning dolphin. Approach dolphins are used where the end of a pier or ends of a slip require protection from incoming ships.

2.1.~~8~~9 Special Orientation and Form. Degaussing/deperming facilities usually require a magnetic north/south orientation, irrespective of other considerations. When both sides of a moored ship need to be accessed, two parallel piers with a slip in between may be preferred. Occasionally, there is also a need to provide a cover over the berthed ship for security or operational considerations, as for the Ohio-class (Trident) submarines. Special moorings may be required for floating drydocks and special considerations for dredging (and shoaling) to allow for lowering of the dock is required. Graving docks are discussed in MIL-HDBK 1029/3, Drydock Facilities.

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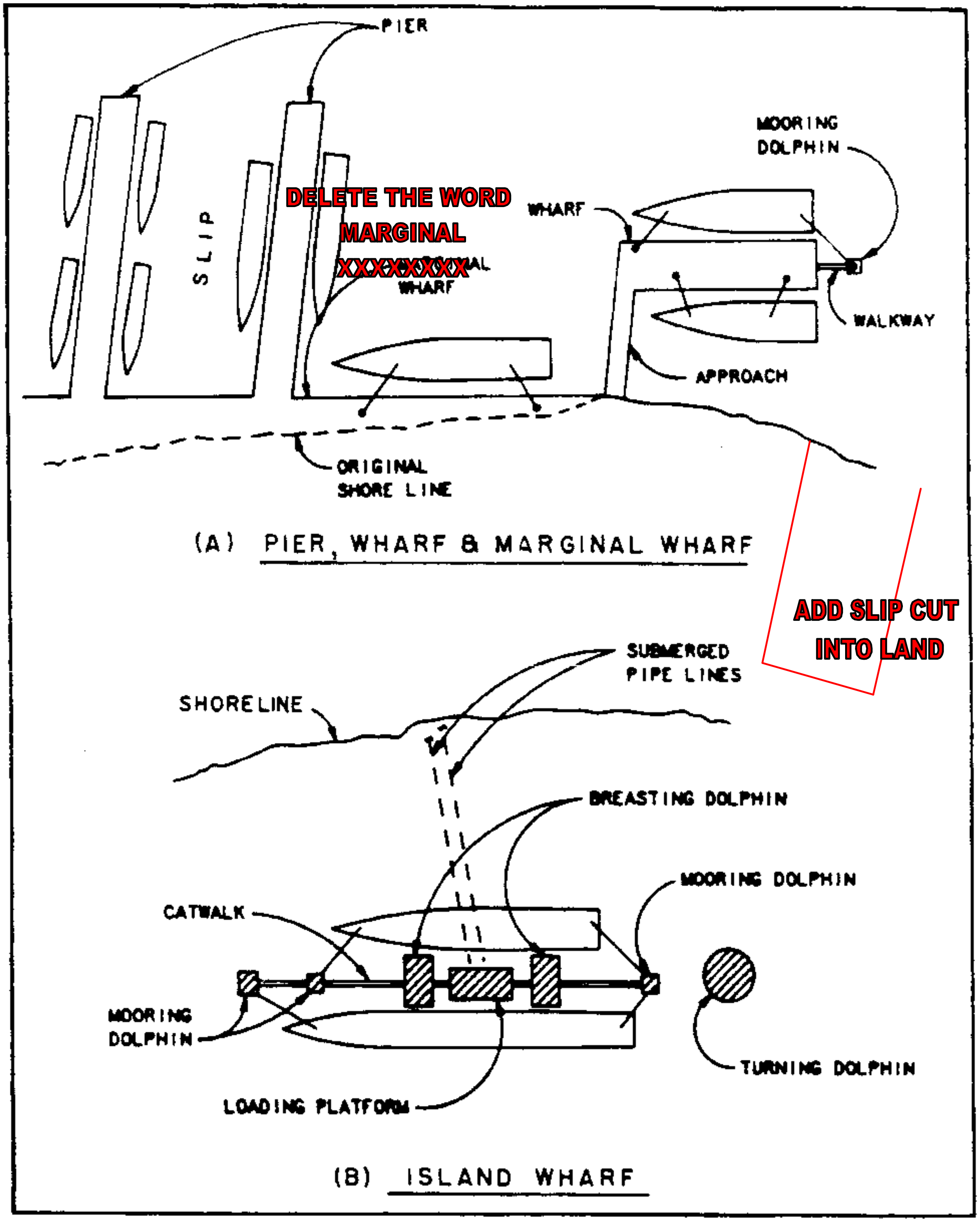

Figure 1
Pier and Wharf Types

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DELETE REF'S TO "MARGINAL" WHARF

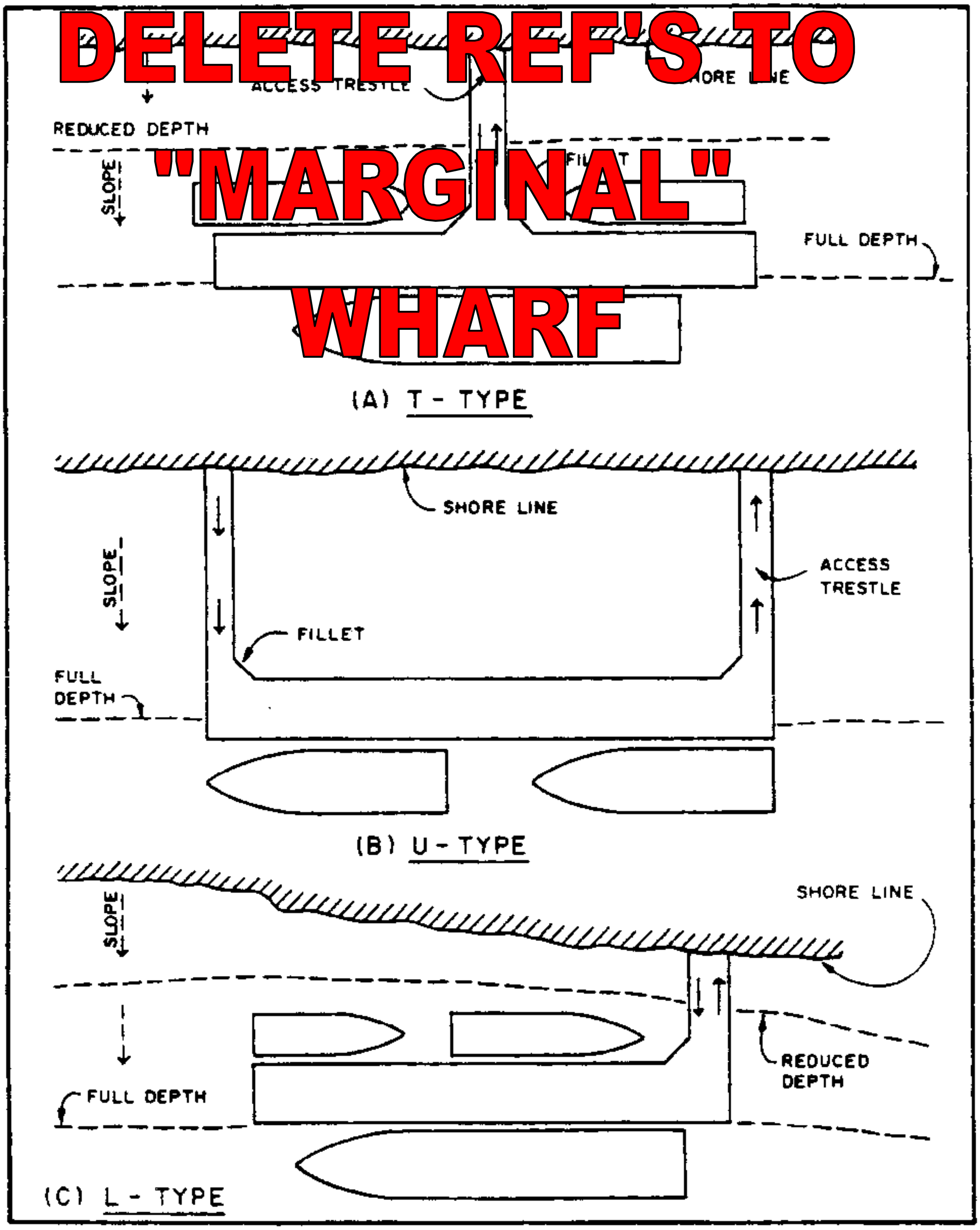

Figure 2
Marginal Wharf Types

2.2 Overall Dimensions and Clearances.

2.2.1 General. The overall dimensions and clearances required for piers and wharves are dependent on characteristics of the ships to be berthed and the support services provided. ~~See Table 1~~ See **SHIPS (ship characteristic database) on the NAVFAC web site** for characteristics of typical ship types. For additional information on general criteria, see Naval Facilities Engineering Command NAVFAC P-80, Facility Planning Criteria for Navy and Marine Shore Installations, and the Naval Vessel Register, and the Military Sealift Command Homepages. See http://www.efdlant.navfac.navy.mil/Lantops_15 for links to the Naval Vessel Register and Military Sealift Command pages. See the NAVFAC website for the latest Interim Technical Guides (ITG's).

2.2.1.1 Ship Characteristics

a. Draft – use the larger limiting draft or maximum navigational draft in determining minimum water depth requirements. The maximum draft for a surface combatant is 33.4-ft (10.2m)(CG 47), for an amphibious warfare, it is 27-ft (8.2m)(LHD 1), and for combat logistics, it is 36-ft (11m)(T-AO-187). Use the limiting draft for the largest CVN in determining minimum water depth requirements; i.e., 40.8 feet.

b. Displacement – use the largest displacement expected of any ship anticiapated to use the facility in determining berthing forces on the pier or wharf. The maximum displacement for surface combatants is 9,962 long tons (10,125 metric tons); for amphibious warfare is 40,674 long tons (41,430 metric tons), combat logistics is 40,000 long tons (40,653 metric tons), and CV or CVN is 104,200 long tons (105,854 metric tons).

c. Length – use the overall length for the longest combination of surface combatants, amphibious warfare, combat logistic ships, or CVN that normally use the facility to determine pier and wharf length and utility locations. Largest overall length for surface combatants is 567-ft (172.8m)(CG 47), for amphibious warfare 884-ft (269.4m)(LHD 1), for combat logistics 677-ft (206.3m) (T-AO-187), and for CVN 1123 ft (342.3m).

d. Breadth – use the widest to determine horizontal clearances and slip width both for single berth and nested configurations. Maximum breadth for surface combatants is 66-ft (20.1m)(DDG 51), for amphibious warfare 118-ft (36m)(LHA 1), and combat logistics 97.5-ft (29.7m)(T-AO-187). Note that the waterline beam for CVN 68-75 is 134 ft and the width of the flight deck structure (with antenna platforms, walkways, and portable flight deck sections removed) is 252 ft. Without removing these appurtenances, CVN 68 is 260 ft and CVN 76 is 280 ft wide.

e. Height – use the lightly loaded height of 180 ft (55m) above the waterline. This includes combined superstructure and all communications / antenna array supported by the superstructure. Governing vessel is the LPD 17. Use the lightly loaded height of 215 ft. above the waterline for

CVN's.

2.2.1.2 Supporting items - provide the following:

a. Fenders / Camel System - Design fender / camel systems for the following arrangements: Single berths for LHD, LHA, multiple berths for LPD, LSD (amphibious warfare); single berths for AO, TAO (combat logistic), and multiple / nested berths for DD 963, CG 47, DDG 51, FFG 7 (surface combatants). Design system for flexibility and to accommodate any unique features of the above ships. For CV and CVN provide three camels (one spare) of minimum width 55 ft. to prevent interference between the ship elevator and the pier deck. Naval Station Norfolk uses 32-ft wide camels but provides a 2 degree list. Naval Station Everett uses 60-ft wide camels. Camels may be barges or fabricated from NAVFACENGCOM standard drawings and specifications. Structurally evaluate barge for severe weather conditions. Also consider crane lift ability in camel design and utility location. NAVSEA PMS 312 recommends 60-ft camels for new CVN homeports. Design systems for flexibility and to accommodate any unique features of the above ships.

b. Aircraft Support - Aircraft require extensive support. Those requirements are not addressed herein.

c. Laydown Area - A minimum of 5 acres (20,234m^2) of laydown area in addition to pier/wharf space is desirable. The laydown area should be within ½ mile (.8km) of the pier/wharf.

e. Brows – Brows and Platforms are usually placed onat ship's designated entry/egress points to the main deck. For CV and CVN, two 45 foot brows are usually placed on the ship's #2 elevator and one 60 foot brow placed between elevators #2 and #3 to the main deck. Brow design length will be based on camel design and resultant standoff distance.

f. Handicap Accessibility – Design facilities (ramps, landings, railings) in accordance with American with Disabilities Act (ADA) of 1990. Technical requirements and guidelines for accessibility to buildings and facilities are found in ICC/ANSI A117.1, Accessible and Usable Buildings and Facilities and the American with Disabilities Act Accessibility Guidelines (ADAAG).

g. Other Ship Use - CVN berths should generally be designed to accommodate a variety of surface combatants that may use the facilities.

h. Warehouse Space - General warehouse space accessible to large trucks and handling equipment.

i. Permit no pier interferences such as utilities and deck appurtenances in the zone of carrier elevators 1, 2, and 3.

2.2.2 Pier and Wharf Length.

2.2.2.1 Single Berth. The length of pier or wharf should equal the overall length of the largest ship to be accommodated, plus an allowance of 50 ft at each end of the ship. For aircraft carriers, the allowance at each end of the vessel should be increased to 100 ft. (See Figure 3.)

2.2.2.2 Multiple Berths. The length of a pier or wharf should equal the total overall length of the largest ships simultaneously accommodated, plus clear distance allowances of 100 ft between ships and 50 ft beyond outermost moored ships. (See Figure 3).

2.2.2.3 Minimum Slip Length - 1350-1500 ft. (412m-457m) min. This range in slip length is based on berthing two CG 47 /lower range and two LPD 17 / upper range which provides adequate space for bow and stern lines, provides a safety and security clearance fore and aft of each berth of 50 ft. (15.2m), and facilitates emergency sorties without tug support. For CVN's , provide 1300 to 1325 ft minimum which allows a safety clearance fore and aft of 100 ft. For CVN's, five to eight tugs should be available for berthing operations.

2.2.2.4 **Container and RO/RO Berths. The length of berths used for container or RO/RO berths should account for the requirements of the container cranes or special ramps. Where shipboard slewing ramps are to be used, provide adequate berth length to allow for efficient vehicle maneuvering.**

2.2.2.5~~3~~ Submarine Berths.

For most classes of submarines, a 50-ft end distance to a quaywall or bulkhead is adequate. The nose-to-tail spacing for multiple berthing should also be a minimum of 50 ft. However, large submarines such as the Ohio class (Trident) require 150 ft or more nose-to-tail spacing and clearance to bulkhead or quay wall. Where explosive safety distance considerations require the use of fragmentation barriers, or specific separation distances, spacing shall be adjusted per the requirements of NAVFAC OP5.

2.2.2.6 **Arrangement** – Provide homeport facilities for the following arrangements: Single berths for LHD, LHA, multiple berths for LPD, LSD (amphibious warfare); single berths for AO, TAO (combat logistic), and multiple / nested berths for DD 963, CG 47, DDG 51, FFG 7 (surface combatants).

2.2.2.7 **CVN Berth. CVN's are typically moored "starboard side to" to allow acess to the ship's three elevators for on/off loading.**

2.2.3 Pier and Wharf Width. Pier width as used herein refers to the net operating width of the structure, exclusive of fender systems, curbs, and dedicated utility corridors. (See Figure 4.) This definition also holds for U-, L-, and T-type wharves. However, with reference to ~~marginal~~ wharves, the width should be the dimension to a building, roadway, or other identifiable obstruction. Refer to Table ~~2~~1 for minimum widths established for each functional type. They should be reviewed with specific functional requirements of the individual installation before a final selection is made. Functional requirements include operational space, space for maintenance of utilities and layout of cables and hoses, space for solid waste collection, space for brows and stair platforms, and space for crane operation. For crane operation, consideration must be given to crane outriggers, tail swing of crane counterweights, and overhang of vessels. For CV's and CVN's, the tail swing of gantry cranes must be coordinated with the overhang of the flight deck and elevators considering available camels and potential list of the ship. Also, these dimensions should not be less than the widths determined by geotechnical and structural considerations. Factors to be considered in the determination of pier and wharf width are as follows:

2.2.3.1 Utilities. One of the primary functions of a pier or wharf is to provide connections for utilities from ship to shore. Fixed utility terminals are usually provided close to the edge of the pier or wharf along the bullrail. Flexible hoses and cables are then connected to these terminals and to the ship. Depending upon the type of utility hoods, the terminals, hoses, and cables may require 10 to 15 ft of space along the edge that cannot be utilized for any other purpose. Consideration should be given to types of utility hoods that require ~~no~~ additional edge space for cable and hose laydown. Sometimes, the electrical vaults or substations are mounted on the deck, further encroaching on the clear operating width available. It ~~is~~ may be preferable to locate them underdeck in watertight concrete vaults to avoid encroachment on available deck space. Where the width of the berth area is constrained by adjacent facilities or other limitations, the use of dual level configurations may be warranted. These configurations allow the utility enclosures and the associated hoses, cables and maintenance activities to be segregated from the operational areas and allow crane operations closer to the edge of the pier or wharf. See Figure 7.

2.2.3.2. Wharves or piers with berths on one side = 66 ft (18.3m) min., (16 ft (4.9m) bollards and utilities, 35 ft (10.7m) mobile crane ops, 15 ft (4.5m). fire lane). For CVN's with berths on one side, = 90 ft minimum (20 ft bollards and utilities, 35 ft mobile crane ops, 15 ft fire lane, 20 ft for loading area.

2.2.3.3. Piers with berths on both sides = Single Deck: 117 ft. (35.7m) min., (32 ft (9.8m) bollards and utilities, 70 ft (21.3m) mobile crane ops/loading area, 15 ft (4.6m) fire lane). Double Deck 93-ft (28.3m) min. (8 ft (2.4m) bollards, 70 ft (21.3m) mobile crane ops/loading area, 15 ft (4.6m) fire lane). The double-deck concept provides clear unobstructed pier to ship interface; isolation of main deck port services operations from lower-deck public works utilities operations; reduced offset requirements for mobile crane operation thereby reducing the requirement for floating cranes; higher main deck, eliminating the need for brow platforms; for out of water transformer vaults. For CVN's with piers on both sides, = 150 ft. minimum (40 ft bollards and utilities, 70 ft. mobile crane ops/loading area, 15 ft fire lane, 25 ft for loading area. This requirement is for carrier (CVN) berths or a combination of CVN/AOE berthed. Recommend 150 ft wide piers based on operational experience of existing facilities.

2.2.3.4   These widths provide adequate space for line handling, utility maintenance, ship maintenance, replenishment, and fire fighting access. Transformers are assumed off-deck or under-deck, deck mounted transformers require additional 25 ft. (7.6m) of pier width.

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Table 1
Characteristics of Typ[illegible]

DELETE TABLE 1

Ship Type	[illegible]	Overall Length (feet)	Extreme Width (feet)	Beam at Waterline (feet)	Max Nav Draft (feet)	Fully Loaded Draft (feet)	Fully Loaded Displacement (long tons)
COMBATANT SHIPS							
Battleship Iowa Class	BB 61	888.0	109.0	108.0	38.0	37.0	58,000
Guided Missile Cruiser	CG 26	547.0	55.0	54.0	30.5	20.5	8,250
Guided Missile Cruiser	CG 47	567.0	55.0	55.0	31.6	20.0	9,600
Guided Missile Cruiser	CGN 36	596.0	61.0	60.0	31.0	21.0	10,450
Guided Missile Cruiser	CGN 38	586.0	63.0	61.0	32.6	21.8	10,420
Aircraft Carrier	CV 66	1048.0	252.0	130.0	38.0	37.0	81,770
Aircraft Carrier Nimitz Class	CVN 68	1092.0	257.0	134.0	41.0	38.0	91,490
Destroyer	DD 963	564.0	55.0	55.0	30.0	21.0	7,810
Guided Missile Destroyer	DDG 2	437.0	47.0	46.0	24.0	16.0	4,900
Guided Missile Destroyer	DDG 37	513.0	53.0	52.0	27.0	14.0	6,120
Guided Missile Destroyer	DDG 993	563.0	55.0	55.0	32.4	20.0	8,300
Guided Missile Destroyer	DDG 51	466.0	60.0	60.0	30.0	--	8,400
Frigate	FF 1052	438.0	47.0	47.0	26.5	16.5	4,330
Guided Missile Frigate	FFG 7	445.0	47.0	38.0	24.9	14.4	3,590
Submarine	SS 567	293.0	27.0	24.0	17.3	16.8	2,030
Submarine Darter Class	SS 576	283.0	27.0	25.0	17.3	16.8	2,030
Submarine Sturgeon Class	SSN 637	289.0	32.0	25.0	29.0	25.8	4,270
Submarine Los Angeles Class	SSN 688	361.0	33.0	29.0	30.5	27.5	6,930
Submarine Lafayette Class	SSBN 616	421.0	33.0	25.0	32.0	27.3	7,350
Submarine Ohio Class	SSBN 726	560.0	42.0	30.0	35.9	35.4	16,740
MINE WARFARE SHIPS							
Minesweeper Countermeasure Vehicle	MCM 1	224.0	--	39.0	--	11.25	1,040
Minesweeper/Hunter, Air Cushion	MSH 1	189.0	39.0	39.0	13.5	8.8	334
Minesweeper	MSO 427	173.0	35.0	35.0	14.0	12.0	930
AMPHIBIOUS WARFARE SHIPS							
Landing Craft, Air Cushion	LCAC 1	88.0	47.0	47.0	--	2.75	170
Amphibious Command Ship	LCC 19	620.0	108.0	82.0	30.0	29.0	18,650
Amphibious Cargo Ship	LKA 113	576.0	82.0	82.0	28.0	28.0	18,650
Amphibious Transport Dock	LPD 4	570.0	105.0	84.0	23.0	17.3	17,240
Amphibious Assault Ship	LHA 1	820.0	118.0	106.0	26.0	26.0	39,400
Amphibious Assault Ship	LHD 1	844.0	106.0	106.0	--	26.1	40,530
Dock Landing Ship	LSD 36	553.0	84.0	84.0	20.0	20.0	13,700
Dock Landing Ship	LSD 41	609.0	84.0	84.0	19.6	19.6	15,730
Tank Landing Ship	LST 1179	565.0	70.0	70.0	20.0	16.0	8,520
AUXILIARY SHIPS							
Destroyer Tender	AD 37	645.0	85.0	85.0	30.0	27.0	20,500
Destroyer Tender	AD 41	643.0	85.0	85.0	--	22.1	19,740
Ammunition Ship	AE 26	564.0	81.0	81.0	31.0	28.0	18,088
Combat Store Ship	AFS 1	581.0	79.0	79.0	28.0	28.0	18,660
Fast Combat Support Ship	AOE 1	796.0	107.0	107.0	41.0	41.0	53,600
Oiler	AO 177	589.0	88.0	88.0	--	32.4	27,500
Replenishment Oiler	AOR 1	659.0	96.0	96.0	36.5	36.5	37,700
Salvage Ship	ARS 38	214.0	43.0	43.0	15.1	14.3	1,970
Salvage Ship	ARS 50	255.0	--	51.0	17.8	17.0	2,880
Submarine Tender	AS 36	644.0	85.0	85.0	30.0	29.0	23,490
Repair Ship	AR 5	530.0	73.0	73.0	26.0	24.0	17,200
Oceanographic Research	T-AGOR 16	246.0	75.0	75.0	22.9	20.1	3,420
Survey Ship	T-AGS 21	455.0	--	62.0	28.8	21.0	13,050
Cargo Ship	T-AK 284	488.0	--	68.0	31.0	31.0	15,404
Vehicle Cargo Ship	T-AKR 287	946.0	--	106.0	37.0	37.0	2,810
Maritime Prepositioning Ship	T-AKX	821.0	--	106.0	32.0	32.0	47,000
Oiler	T-AO 187	678.0	--	97.0	--	34.5	40,000
Transport Oiler	T-AOT (TS)	615.0	--	90.0	--	34.0	39,000
Fleet Ocean Tugs	T-ATF 166	226.0	--	42.0	--	15.0	2,260

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COORDINATE TABLE WITH INSERTED INFO FROM ITG'S

CHANGE TO TABLE "1"

Table 2
Typical Single-Decked Pier and Wharf Widths

Function Classification	Ship Type	Minimum Pier Width (feet)	Minimum Wharf Apron Width (feet)	Railroad Tracks (standard gage)	Rail-Mounted Cranes
Ammunition	Ammunition	100	100	--	[illegible]
Berthing	Aircraft Carrier*	100	[illegible]	--	[illegible]
Berthing	All Others	80	--	--	[illegible]
Berthing	Submarines	60	--	--	--
Fitting-out	Destroyer	125	--	2 tracks 1 each side	2 40-foot gage 1 each side
Repair	Cruiser	125	--	4 tracks 2 each side	2 40-foot gage 1 each side
	Auxiliary	125	--	4 tracks 2 each side	2 40-foot gage 1 each side
Fueling	Auxiliary	50	--	--	--
Supply (general cargo)	Auxiliary	125+	80	2 tracks	--
Supply (container cargo)	Auxiliary	125	125	Up to 3 tracks	1 100-foot gage

* Width applies when 60-foot camels are used to breast out carriers.

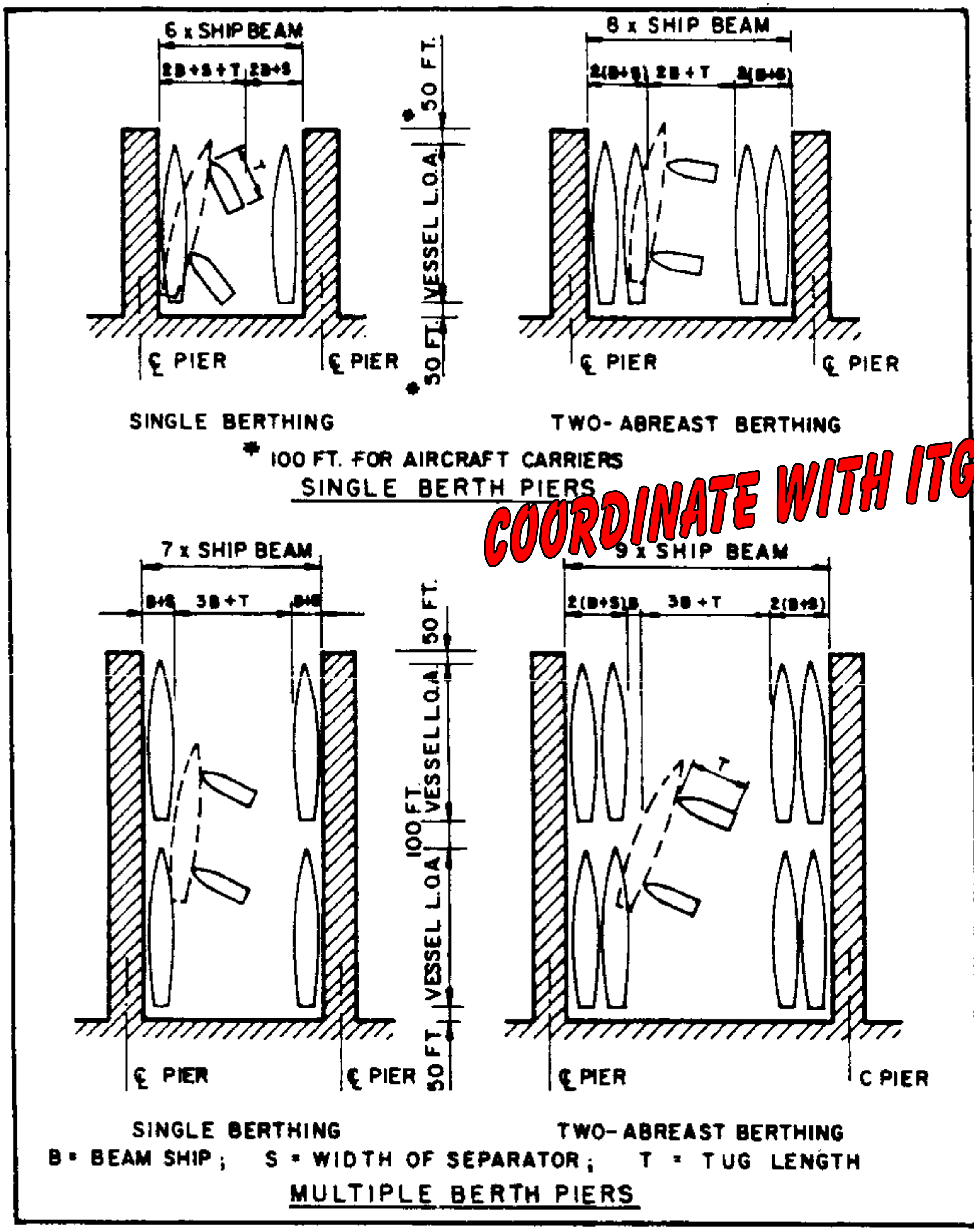

Figure 3
Length and Width of Slip

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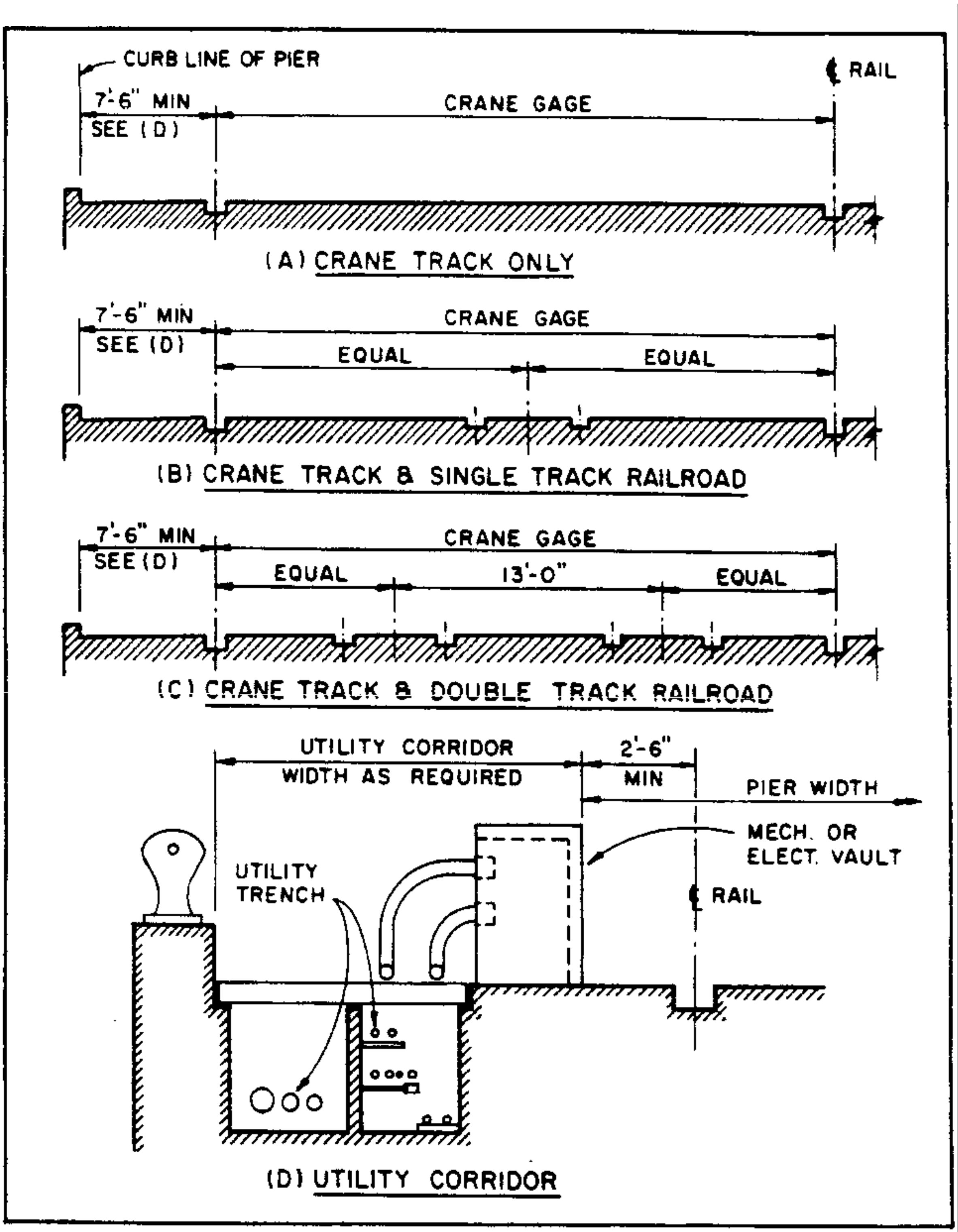

Figure 4
Location of Utility Corridor, Crane, and Railroad Tracks

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2.2.3.5~~2~~ Mobile Crane Operation. Piers and wharves are subject to frequent usage by truck-mounted mobile cranes forklifts, and straddle carriers for servicing the ships. This weight-handling equipment requires maneuvering and turnaround space on the deck for effective operation. If possible the deck space should be planned to allow mobile cranes to be backed up perpendicular to the bullrail. This permits the maximum load/reach combination. Make allowance for tail-swing of crane counter-weight. Refer to MIL-HDBK 1038/1 and P-307. The Navy Crane Center at {Identify contact point for Navy Crane Center!} may be consulted for operating requirements.

2.2.3.6~~3~~ Crane Tracks. Rail-mounted cranes are often needed for ship fleet loadout in outfitting/refit and repair facilities. Width requirements depend on equipment selected. A rail gage of 40 ft is standard(?) for new cranes, except at container terminals or where it is necessary to conform to gages of existing tracks. When cranes are furnished, the distance from the waterside crane rail to the edge of the pier or wharf should be adequate to provide clearance for bollards, cleats, capstans, pits housing outlets for ship services, crane power conductors, and other equipment. Some electric powered gantry cranes may require either open or covered (panzer-belts) cable trenches in the pier or wharf deck for the power conductors. Where aircraft carriers or other ship types with large deck overhangs are anticipated to be berthed, the crane rail should be located so that all parts of the crane will clear the deck overhang. For discussion of crane power conductors, see ~~Naval Facilities Engineering Command NAVFAC DM-38.01~~MIL-HDBK 1038/1, Weight Handling Equipment. **For trackage requirements, refer to MIL-HDBK 1005/6, Trackage.**

2.2.3.7~~4~~ Railroad Tracks. For supply and ammunition piers and wharves, railroad service should be considered. Except where local conditions require otherwise, standard gage should be used for trackage. For standard gage and spacing between adjacent tracks, see Naval Facilities Engineering Command~~ NAVFAC DM-5.06~~ MIL-HDBK 1005/6, **Trackage**~~, Civil Engineering - Trackage~~. Width of piers and wharves should be adequate to allow passing of trains and forklift trucks (or other material-handling equipment). Allowances should also be made for stored cargo and other obstructions.

2.2.3.8~~5~~ Trucks and Other Vehicles. A variety of service trucks and vehicles can be expected to use piers and wharves for moving personnel, cargo, containers, and supplies to and from the ships. The width provided must take into account operation and maneuvering of such vehicles. Turnaround areas should be provided.

2.2.3.9~~6~~ Sheds and Buildings. Pier and wharf deck is usually too expensive an area for storage sheds, which should therefore be located on land to be cost-effective. However, small buildings to provide for berthing support and storage of equipment may sometimes need to be accommodated on deck.

2.2.3.10~~7~~ Movable Containers and Trailers. During active berthing of ships, various containers of different sizes are temporarily or permanently located on pier deck to support the operations. These include shipyard toolboxes, garbage dumpsters, training trailers, and supply trucks. Adequate deck space should be available for locating and accessing these containers and trailers.

2.2.3.11~~8~~ Fire Lane. For piers, provide a 15-foot-wide unobstructed fire lane independent of net operating width requirements. Locate and mark the lane near the longitudinal pier centerline. For wharves, provide a 15-foot-wide unobstructed fire lane immediately adjacent to the operating area. These requirements ~~should~~ need not be applied to small craft or yard craft piers.

2.2.3.12~~9~~ Fuel-Handling Equipment. At specified berths, stationary fuel-handling equipment consisting of self-adjusting loading arms are often furnished to offload fuel products from tankers to onshore storage facilities. Pier or wharf width requirements depend on equipment selected and facilities furnished.

2.2.3.13~~0~~ Phased Maintenance Activities (PMA). At some naval stations, PMA performed at berth~~ing piers~~ will be of significant magnitude. Requirements for space and pier or wharf dimensions due to PMA should be considered for these ~~piers~~ locations. For additional information, see Naval Civil Engineering Laboratory NCEL TM-5, Advanced Pier Concepts, Users Data Package and OPNAVINST 4700.7J, "Maintenance Policy of Naval Ships". The four levels of PMA and their estimated space requirements are as follows and as detailed in Table ~~3~~2.

a) Intermediate Maintenance Availability (IMA). IMA consists of removal and repair of shipboard equipment performed by Shore Intermediate Maintenance Activity (SIMA) personnel or tender forces, with a duration of approximately 30 days. Gross deck requirements range from 2000 to 3000 ~~ft+2+~~square feet with work area dimensions varying from 30 x 65 ft to 30 x 100 ft.

b) Planned Restricted Availability (PRA). PRA consists of limited repairs of shipboard equipment and systems by contract forces under Supervisor of Shipbuilding and Repairs (SUPSHIP) control, with a duration of 30 to 60 days. Gross deck area requirements are about 10,800 square feet ~~ft+2+~~ (35 x 310 ft). On a double deck pier with adequate clearance, about 5,000 square feet of command and storage area could be on the lower level.

c) Selected Restricted Availability (SRA). SRA consists of expanded repairs and/or minor ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of approximately 60 days. Gross deck area requirements are about 18,000 square feet~~ft+2+~~ (35 x 515 ft). On a double-deck pier with adequate clearance, about 5000

~~ft+2+~~square feet of command and operational area could be on the lower level

d) Regular Overhaul (ROH). ROH consists of major repairs and ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of six to eight months. Gross deck area requirements are about 23,000 square feet~~ft+2+~~ (35 x 660 ft). In addition, there would be a requirement for turnaround areas on deck and warehousing off the pier or wharf. On a double-deck pier, up to 8000 square feet~~ft+2+~~ of command and operational area could be on the lower level.

Table 2~~3~~
Estimated Space Requirements for PMA

Activity	PRA	SRA	ROH
COMMAND AREA			
Mobile Administration Building	-	2,800	5,600
Parking Area	250	250	500
Bicycle Racks	70	140	200
Subtotal	320	3,120	6,300
OPERATING AREA			
Demineralizer	-	1,500	1,500
Bilge Water/Stripping Tank	-	400	400
Dumpsters	1,150	1,440	1,730
Portable Solid-State Generators	-	240	240
Air Compressors	290	290	290
Welding	1,500	1,500	1,500
Flammable Storage	150	600	600
Transportation Laydown	600	900	1,500
Crane Work	3,850	3,850	5,250
Offload Area (oils, fuels, etc.)	3,00	3,600	4,500
Potable Heads	-	70	70
Additional Brow	-	400	400
Subtotal	10,540	14,790	17,980
Total	10,860	17,980	24,280

2.2.4 Slip Width.

2.2.4.1 General Considerations. The clear distance between piers, or slip width, should be adequate to permit the safe docking and undocking of the maximum size ships that are to be accommodated in the slip. The size of a slip should also permit the safe maneuvering and working of tugboats, barges, lighters, and floating cranes. At multiple berth piers, where ships are docked either one per berth, two abreast per berth, or more, sufficient clearance should be available to permit the docking and undocking of ships at the inboard berth without interfering with ships at the outboard berth. Because the size of a slip is affected by docking and undocking maneuvers, consideration should be given to the advice of local pilots who are familiar with the ships to be handled and with prevailing environmental conditions such as winds, waves, swells, and currents. Slip width is also influenced by the size and location of separators used between ship and structure and between ships. The width should be reviewed with specific functional requirements of the individual installation before a final determination is made.

2.2.4.2 Minimum Width of Slip for Active Berthing Minimum slip width: Location of homeport berthing facilities should allow nesting of DDG 51 / CG 47 / DD 963 / FFG 7 class ships. Minimum slip width for surface combatant multiple, nested configuration is 600-ft. (183m). Minimum slip width for single amphibious warfare and combat logistic ship berths is 600-ft. (183m). {need to coordinate this info from the ITG with Figure 3}.

2.2.4.3 For CVN's, minimum width shall be 600 ft. with no other ships, 800 ft. with CVN on opposite berth. Add 100 ft to width if ships are berthed at the bow or stern.

2.2.4.4 Minimum width should be the greater of the two dimensions shown on Figure 3. Additionally, the width should not be less than 300 ft. The recommended criteria are applicable only if ships are turned outside the slip area. Refer to ~~Table 1~~ **SHIPS (ship characteristic database) on the NAVFAC web site** for the beam of typical ship types. At submarine slips, width requirements should be increased by at least four beam widths to account for camels and separators, to provide for ships' vulnerability if their safety is involved, to provide for special maneuvering requirements of other ships during berthing or passing, and to provide for special environmental conditions such as currents, waves, and winds. The requirements discussed above apply where ships are berthed on both sides of a slip. Where ships are berthed on only one side of a slip, the width may be reduced. See Figure 3. When more than two-abreast berthing is employed, the width of slip should be increased by one ship beam for each additional ship added in order to maintain adequate clearances between moored ships during berthing and unberthing maneuvers. Thus, for three-abreast berthing on both sides of a slip, the slip width for single-berth piers would be equal to 10 times ship beam and the slip width for multiple-berth piers would be equal to 11 times ship beam.

2.2.4.~~3~~5 Minimum Width of Slip for Inactive Berthing. At slips containing inactive berths where ships are stored for long periods of time on inactive status in nests of two, three, or more, clear distances between moored ships and slip width may be reduced by one or two ship beams to reflect the reduction in the frequency of berthing maneuvers and the decrease in activities of small boats and floating equipment.

2.2.5 Water Depth in Slips

2.2.5.1 Minimum Depth of Water. In a sheltered site and where the site bottom consists of soft material, the water depth in a slip, as measured from mean low water (MLW) level or mean lower low water (MLLW) level, should be equal to the maximum navigational draft of the ships to be accommodated plus a minimum clearance of 4 ft. The maximum navigational draft represents the distance in ft, with the ship in the full load condition, from the waterline to the keel, and below the keel to encompass such projections as sonar domes, extending propellers, vertical submarine control planes, and hydrofoils fitted to various type ships. For the maximum navigational draft of typical ship types, refer to ~~Table 1~~ SHIPS (ship characteristic database) on the NAVFAC web site. The minimum depth of water for aircraft carriers (CV, CVN) and fast combat support ships (AOE) should be 50 ft in order to reduce the extent of sea suction fouling of condensers. Specified water depths should be maintained as close to the fender line of the structure as is practicable considering the accessibility of dredging equipment used during maintenance dredging operations. Minimum slip depth -- 45 ft (13.7m). min. at Extreme Low Water (ELW). The requirement at ELW is based on preventing grounding. For CVN's provide minimum slip depth of 49.5 ft at Mean Lower Low Water (MLLW) and 45.5 ft. at Extreme Low Water(ELW). Over time, siltation occurs in most slips and should be quantified initially. The design depth should then be deeper than the minimum to accommodate siltation over at least 3 years. Siltation may be mitigated through advance maintenance dredging or other means. Also, determine whether the proposed depth is great enough to avoid interference with the vessel's hull and special electronic apparatus that might be attached. This depth provides protection against condenser fouling and grounding, and accommodate variability in displacement, list and trim. See NAVSEA ltr 11460 Ser 03D3/242, dated 3 Jan 95, "CVN 68 Class Water Depth Requirements"

2.2.5.2 Clearance Considerations. The minimum clearance of 4 ft between the ship and the bottom is applied in order to prevent grounding or damage to the ship. The minimum clearance of 4 ft is comprised of an allowance of 1 ft for ship trim in loading, 1 ft for tidal variations, and 2 ft for safety clearance. The minimum clearance of 4 ft should be increased if any of the following conditions prevail:

a) Harbor bottom consists of a hard material such as rock.

b) Excessive silting is 1 ft/year or more.

c) Slip area is exposed to waves, swells, and winds.

d) Extreme low water is 1 ft or more lower than MLW (MLLW).

2.2.6 Pier and Wharf Deck Elevation. Deck elevation should be set as high as possible for surface ship berthing and as low as possible for submarine berthing, based on the following considerations:

2.2.6.1 ~~Overflow~~Overtopping To avoid overflow, deck elevations should be set at a distance above mean higher high water (MHHW) level equal to two thirds of the maximum wave height, if any, plus a freeboard of at least 3 ft. Bottom elevation of deck slab should be kept at least 1 ft above extreme high water (EHW) level. Where deck elevation selected would result in pile caps or beams being submerged partially or fully, consideration should be given to protecting the reinforcing from corroding.

2.2.6.2 Ship Freeboard. Consideration should be given to the varying conditions of ship freeboard in relation to the use of brows and the operation of loading equipment such as conveyors, cranes, loading arms, and other material handling-equipment. Fully loaded ships at MLW (MLLW) level and lightly loaded ships at MHW (MHHW) level should be considered for evaluating the operation of such equipment.

2.2.6.3 Utilities. Deck elevations should be set high enough above HHW levels to allow for adequate gradients in drainage piping and to avoid flooding of drainage and utility manholes. ~~Utilidors~~Utility trenches, utility tunnels, and vaults should be kept above MHW (MHHW) level as much as possible.

2.2.6.4 **Deck Elevation for CVN Berths.** Deck elevation must not conflict with CVN elevators. When lowered, the lowest projection of the elevator is 9.0 ft above the water for a fully loaded CVN. Camels generally provide enough standoff to prevent interference. However, camels of narrower width may result in interference.

2.2.6.~~4~~5 Adjacent Land. Deck elevation should, if possible, be set as close as possible to the adjacent land for smooth access of mobile cranes, service vehicles, personnel vehicles, and railroad. Ramps may be used to access the deck set higher or lower than adjacent land. A gradient less than 15 percent may be used for such ramps when railroad access is not provided. Ramps for pedestrian access should have a gradient less than 12 horizontal to 1 vertical, with 5 foot minimum landings for every 30 inches of rise to conform to Federal ADA requirements. Vertical curves should be large enough so that long wheel base or long overhang vehicles do not high center or drag. Where track-mounted cranes are specified, all the deck areas serviced by the crane should be kept at the same elevation.

2.2.6.~~5~~6 Special Situations. For double-decked piers or wharves and in situations where a sloping deck is contemplated (for gravity flow of sewer lines), all the above considerations should be evaluated. The overflow criteria should be applied to the lower deck of a double-decked pier and the low point of a sloping pier deck.

2.3 Operations.

2.3.1 Railroad and Crane Tracks. The number of railroad and crane tracks required and type of weight-handling equipment furnished on piers and wharves are dependent on the type of function, ships to be accommodated, amount of cargo to be handled, and rate of cargo transfer. Specific service requirements of the individual installation should be evaluated in conjunction with the following considerations:

a) Railroad trackage should not be considered for use on berthing piers and wharves (both active or inactive), except at stations where most cargo is received by rail, one or more tracks may be considered for use on active berthing piers. When there are existing railroad networks at the station, tracks should be considered for installation on repair, fitting out, ammunition and supply piers, and wharves.

b) When trackage is required along aprons of piers and wharves, at least two tracks should be provided so that one track may be used as a running track when the other track is occupied.

c) The use of wide-gage crane service at repair, fitting out, ammunition and supply piers, and wharves should be considered. Track gage should conform to gage of existing trackage on adjacent piers and wharves to avoid creation of "captive" cranes. The merit of rail-mounted crane service should be evaluated in relation to mobile crane service for berthing piers.

d) Where locomotive cranes are used on piers and wharves, the distances between tracks and curbs should be increased to accommodate the tail swings of the crane.

e) Where sponsons or flight decks of aircraft carriers overhang berthing facilities, railroad and crane tracks must be kept clear of all overhangs.

f) Railroad and crane trackage should not be considered for use on piers and wharves used primarily for fueling operations.

g) When railroad and crane trackage is required on piers and wharves, the spacings shown on Figure 4 may be used as a guide.

2.3.2 Mobile Cranes. All piers and wharves should anticipate mobile crane operations on deck, except fueling and degaussing/deperming facilities where a light-duty mobile crane and/or forklift truck is sufficient. Typically, the cranes will be used to lift light loads (5 to 10 tons) but at a longer reach. This requires a high-capacity crane. If the crane operations are not allowable because of ~~utilidors~~ utility trenches and trenches with light-duty covers, such areas should be clearly marked and separated by a raised curb to prevent accidental usage. Typically, mobile crane operators want to get as close as possible to the edge of the pier or wharf to reduce the reach. However, the edges of piers and wharves are also the best places for locating utility trenches and ~~utilidors~~utility trenches. This conflict can be resolved by either designing all utility covers to the high concentrated load from the mobile crane (which can have a very high cost penalty) or by allowing crane operations in discrete and dedicated spaces along the edges, as shown in Figure 5. The conflict can also be resolved through two-story piers where the utilities are kept in the lower story, thus freeing up all the upper story for crane operations. See the Navy Crane Center /P-307 for specific information.

2.3.3 Sheds and Support Buildings. Storage sheds and buildings of any kind should be kept off piers and wharves unless their location can be justified by security considerations. When evaluating on-pier versus upland locations, the cost of the supporting pier deck should be included in the on-pier option. Transit sheds may be considered on piers and wharves where a suitable upland area is not available. When used on a pier, the transit shed should be located along the centerline with clear aprons on both sides consistent with the requirements set forth herein but not less than 20 ft or more wide. On wharves, transit sheds and support buildings should be located on the land-side edge with a clear apron toward the waterside. In general, support buildings on piers and wharves should be kept as small as feasible and located away from high-activity areas for least interference.

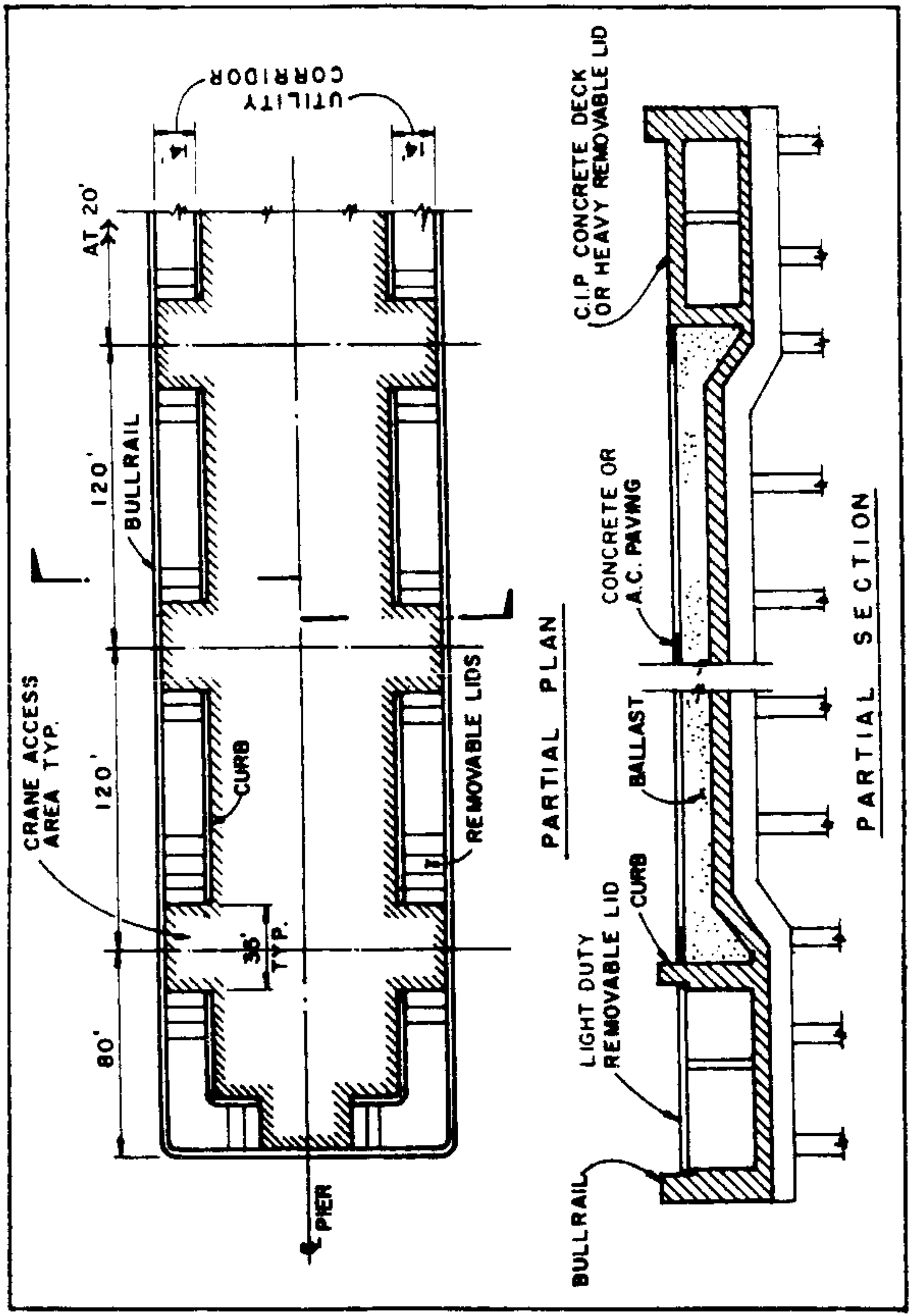

Figure 5
Mobile Crane Operation on Pier Deck

2.3.4 Utilities. For design criteria of utilities on piers and wharves, refer to Naval Facilities Engineering Command ~~NAVFAC DM-25.02~~MIL-HDBK 1025/2, , Dockside Utilities for Ship Service. Usually, utility connection points (hoods, vaults, or mounds) are located and spaced along the pier or wharf edge to be as close as possible to the ships' utility terminals in the assumed berthing position. The connection points should be planned and located to accommodate reasonable future changes in berthing plan or in the type of ships served. Typical services are freshwater (potable, industrial, cooling, etc.), saltwater, chilled water, hot water, steam, sewer (storm, sanitary, oily waste, etc.), air (high pressure, low pressure, breathing, etc.), electrical power, communication wiring, oil, and fuel. All utility lines should be kept ~~above deck~~ where they can be conveniently accessed from above deck. However, infrequently accessed electrical equipment such as transformers can be left below deck in watertight vaults. Where unavoidable, storm and sanitary sewers designed for gravity flow may be located below deck, but as close to the deck as possible. Utility lines suspended below deck are subject to deterioration (of pipes as well as supports) from exposure to seawater and entanglement from floating debris and ice. It is also very difficult and expensive to inspect and service utility lines that do not function very well. The accommodation of utility lines above deck can be accomplished in a number of ways:

2.3.4.1 ~~Utilidors~~Utility Trenches These are basically protected trenches running along the waterside edge of a pier or wharf accessed by removable covers from the top, as illustrated in Figure 6(A). In a pier, the lines can go along one edge all the way to the end and be "looped" to the other edge back to land. In a ~~marginal~~ wharf, the lines can be supplied and returned through smaller lateral "trenches." Where the number and size of lines are large enough, a utility tunnel or gallery can be utilized with access from the top or side. Where a fuel line is provided, it should be kept in a separate trench for containment of leaks.

2.3.4.2 Ballasted Deck. This concept, illustrated in Figure 6(B), consists of a sloping deck filled with 1 ft 6 in. to 3 ft of crushed rock ballast, which provides a convenient medium to bury the utility lines and crane or rail trackage. The ballast is topped with concrete or asphalt paving, which will provide a firm-working surface for operations. The paving and ballast can be opened up and the lines can be serviced as is done on city streets. Concrete pavers have been used successfully for paving ballasted decks and provide improved access to utilities buried in the wharf ballast. Future changes in utilities and trackage can similarly be accommodated. Also, the ballast helps to distribute concentrated load to the deck slab, thus allowing heavier crane outrigger loads.

2.3.4.3 Two-Story Deck. This concept, illustrated in Figure 7, isolates the utility lines into the lower deck along galleries ~~which~~ that are accessed continuously from inside the lower deck. The upper deck is thus clear of all utility lines and terminations and is free for other activities.

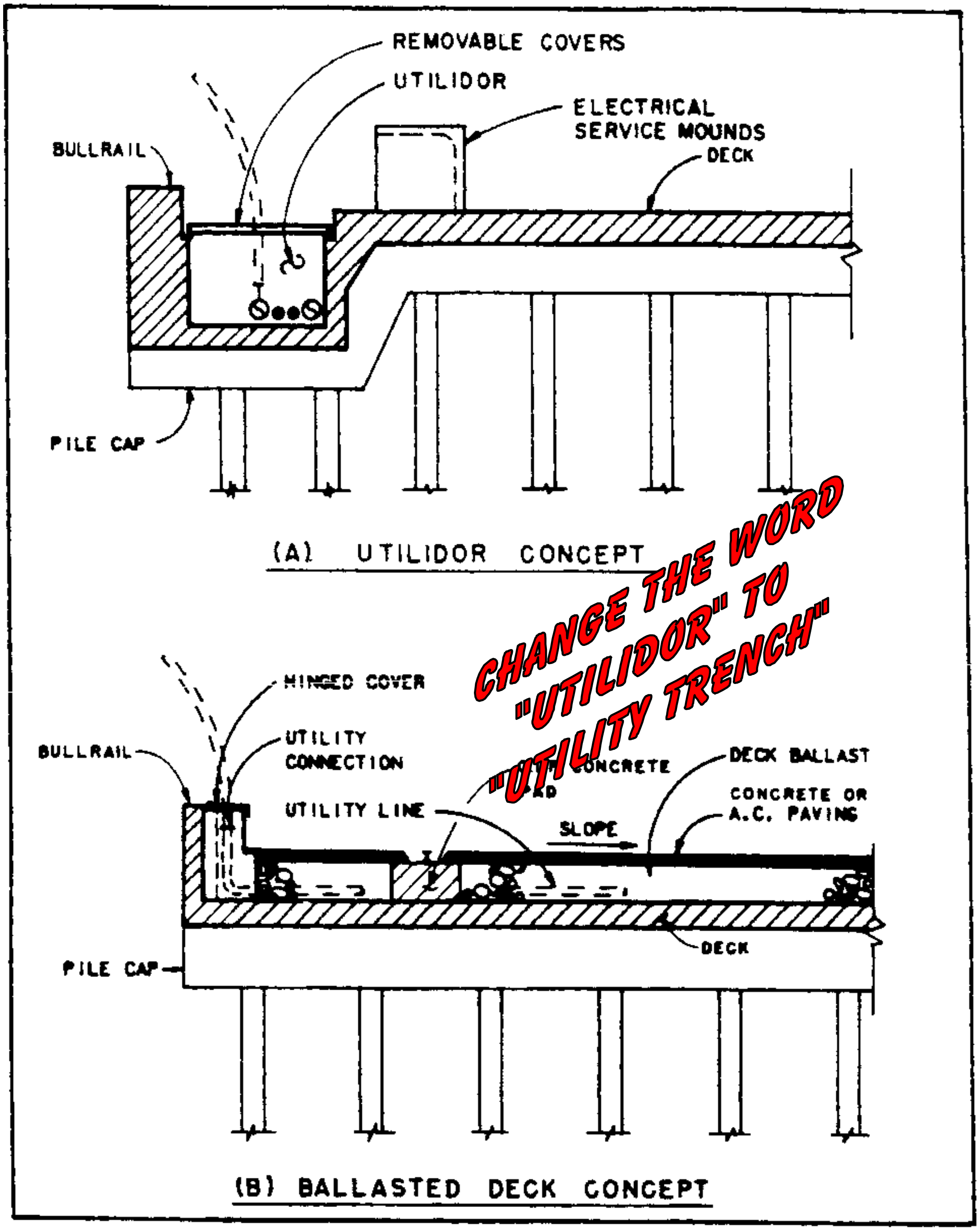

Figure 6
Utility Concepts

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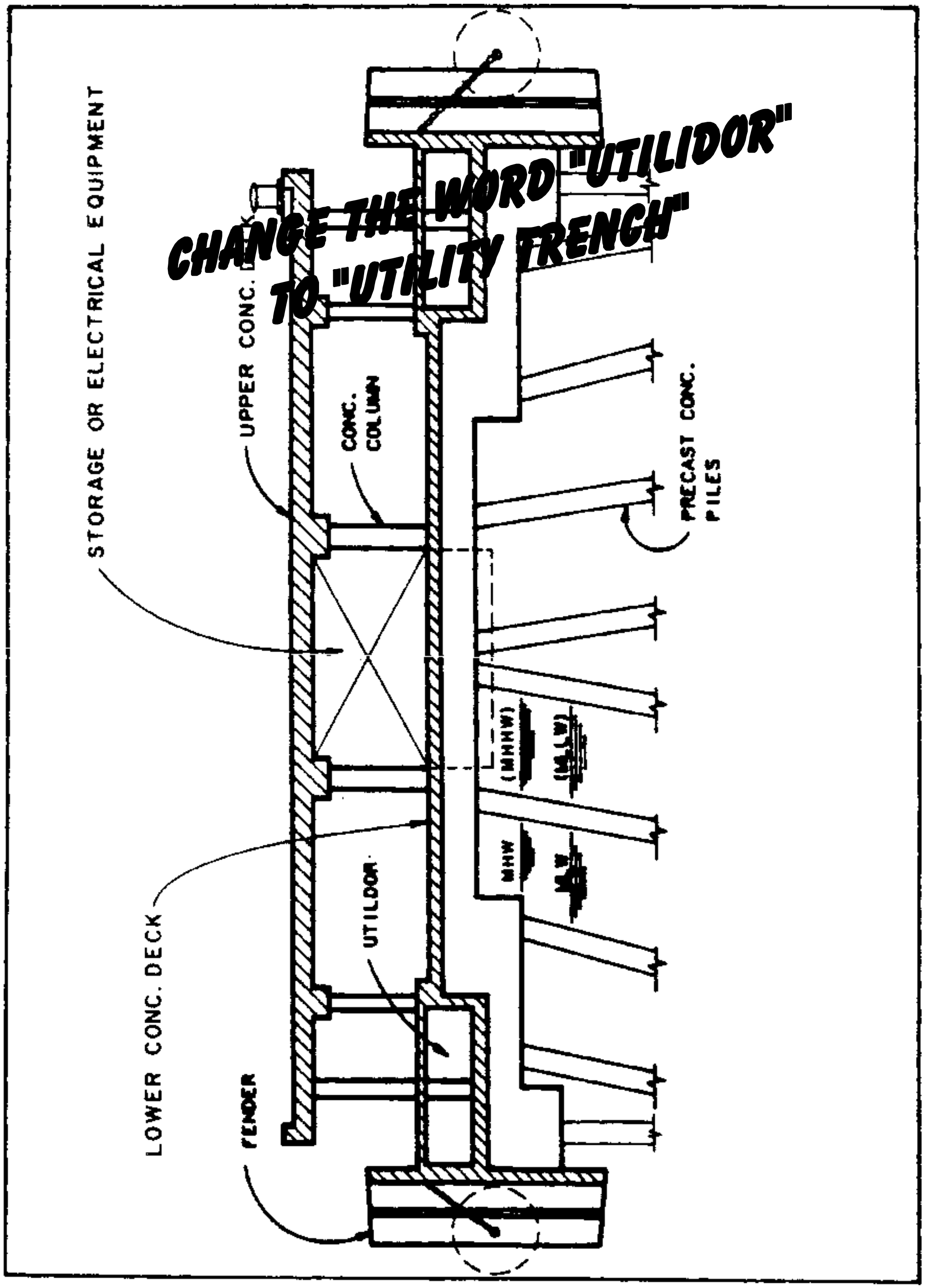

Figure 7
Two-Story Deck Concept

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2.3.5 Lighting.

2.3.5.1 **Light Poles.** Above-pier lighting is needed for security, safety, and support of nighttime pier activities. ~~Under-pier lighting is required for security.~~ Above-pier deck lighting should be accomplished by a few tall poles supporting a battery of light fixtures. The poles require large concrete pedestals and hence should be located so as not to be an obstruction for pier operations. Light fixtures should be located high enough and shielded to light up the pier or wharf deck and waterside edges without blinding the ship's pilots during berthing operations.

2.3.5.2 Under Deck Lighting. Under pier lighting is required for security. As with all under deck utilities, these lights are difficult to maintain.

2.4 Landside Approaches.

2.4.1 Function. Approaches are required to provide access from shore to piers and wharves located offshore. Usually, the approach is oriented at right angles to the shoreline. Except in special situations, approaches should consist of open-type trestle structures that minimize impediments to water flow and disturbances to the characteristics and ecology of the shoreline. The number, width, and orientation of approaches should consider the volume of traffic flow, circulation of traffic, existing roads on shoreside, fire lane requirements, and interruption of service due to accidental collision damage to the approach. As approaches are also used to route utilities to the pier or wharf, the width of approaches will be further influenced by the space requirements of the utility lines being carried. Vehicle and pedestrian approach can usually be combined on the same structure. However, where a large number of personnel are anticipated to access the facility, a separate pedestrian approach should be considered.

2.4.2 Roadway Width. For infrequently accessed facilities (such as deperming/degaussing piers and wharves), the approach roadway should have a minimum width of 10 ft curb to curb for one-lane vehicular traffic. An additional 2-ft width or a separate walkway 3 ft wide attached to the approach structure may be considered if a higher pedestrian volume and frequency of use can be expected.

a) For fueling piers and wharves, the approach should have a minimum width of 15 ft curb to curb for clear access of emergency vehicles.

b) For all other functional types, a two-way 24-ft-wide curb-to-curb roadway should be provided. If two separate one-way approaches are provided for a pier or wharf for incoming and outgoing traffic, each of them may be 12 ft wide curb to curb. In any case, the approaches should be wide enough to permit fast movement of all vehicles anticipated for use on the facility, including emergency vehicles and mobile cranes.

2.4.3 Walkway Width. Separate walkway structures should have a minimum clear width of 3 ft. Where the walkway is attached to a vehicle traffic lane, a minimum width of 2 ft 6 in. clear, from curb to safety railing, should be provided.

2.4.4 Roadway Deck Elevation. The requirements for pier and wharf deck elevation are also applicable to the approaches. Where the adjacent land is higher or lower than pier or wharf, the approach can be sloped up or down to serve as a transition ramp. For approaches longer than 100 ft, the slope should be limited to 6 percent. For shorter approaches, the maximum slope should be 8 percent, 12H:1V.

2.4.5 Number of Approaches.

2.4.5.1 One Approach. For fueling and degaussing/deperming facilities, at least one single-lane approach structure should be provided, unless the facility is built as an island wharf or pier with access by watercraft.

2.4.5.2 Two Approaches.

a) Where volumes of vehicular movements are large, at least two approaches should be provided to ensure continuous uninterrupted traffic flows from pier or wharf to shore. At multiple-berth facilities, approach structures at least every 500 ft should be considered.

b) Where the width of the pier or wharf is not sufficient to permit turning of vehicles, two approaches should be provided. Thus, vehicular traffic may enter and leave the facility without having to turn around. Generally, as it is easier for a truck in tight quarters to negotiate a left turn, traffic patterns should be designed to favor left turns.

2.4.5.3 Railroad Access. Where railroad access is planned, a separate approach is not necessary. However, a separate walkway should be considered.

2.4.6 Turning Room. At the intersection of approach and piers and wharves, fillets or additional deck area should be provided at corners to allow for ease in executing turns. Where a one-lane approach roadway is provided as the only access, the pier or wharf should have sufficient turnaround space on the facility so that outgoing vehicles do not have to back out along the approach.

2.4.7 Safety Barriers. On all approaches, provide safety barriers adequate for the type of traffic using the facility (pedestrian, vehicular, and/or rail). However, safety barriers should not be provided in areas where mission operations, such as ship or small-craft berthing, are performed. Rail-only approaches do not normally require safety barriers. Provide traffic barriers between pedestrian and traffic lanes. Provide anti-terrorism barriers at entrances to piers or waterfront secured areas and avoid straight unimpedded lanes at access ways that would allow high speed forced entry. See MIL-HDBK 1013/14, Selection and Application of Vehicle Barriers for guidance, such as dropping arm or pop-up barriers. Traffic and pedestrian barrier design shall conform to AASHTO Guide Specifications for Bridge Railings and AASHTO Bridge Guide and Manual Interim Specifications.

2.5 Structural Types.

2.5.1 General. The three major structural types for piers and wharves are open, solid, and floating. Open-type piers and wharves are pile-supported platform structures that allow water to flow underneath. Figure 8(A) illustrates the open type. Solid type uses a retaining structure such as anchored sheet pile walls or quay walls, behind which a fill is placed to form the working surface. Solid type will prevent stream flow underneath. Figure 8(B) illustrates the solid structural type. Floating type is a pontoon structure that is anchored to the seabed through spud piles or tension lines and connected to the shore by bridges or ramps. The top of the pontoon can be utilized as the working deck, as shown in Figure 9(A), or a separate column-supported working deck can be constructed on top of the pontoon, as shown in Figure 9(B). Floating structures by definition are not affected by tidal fluctuations, but they do interrupt the streamflow to some extent. All structure types can be either single or double level.

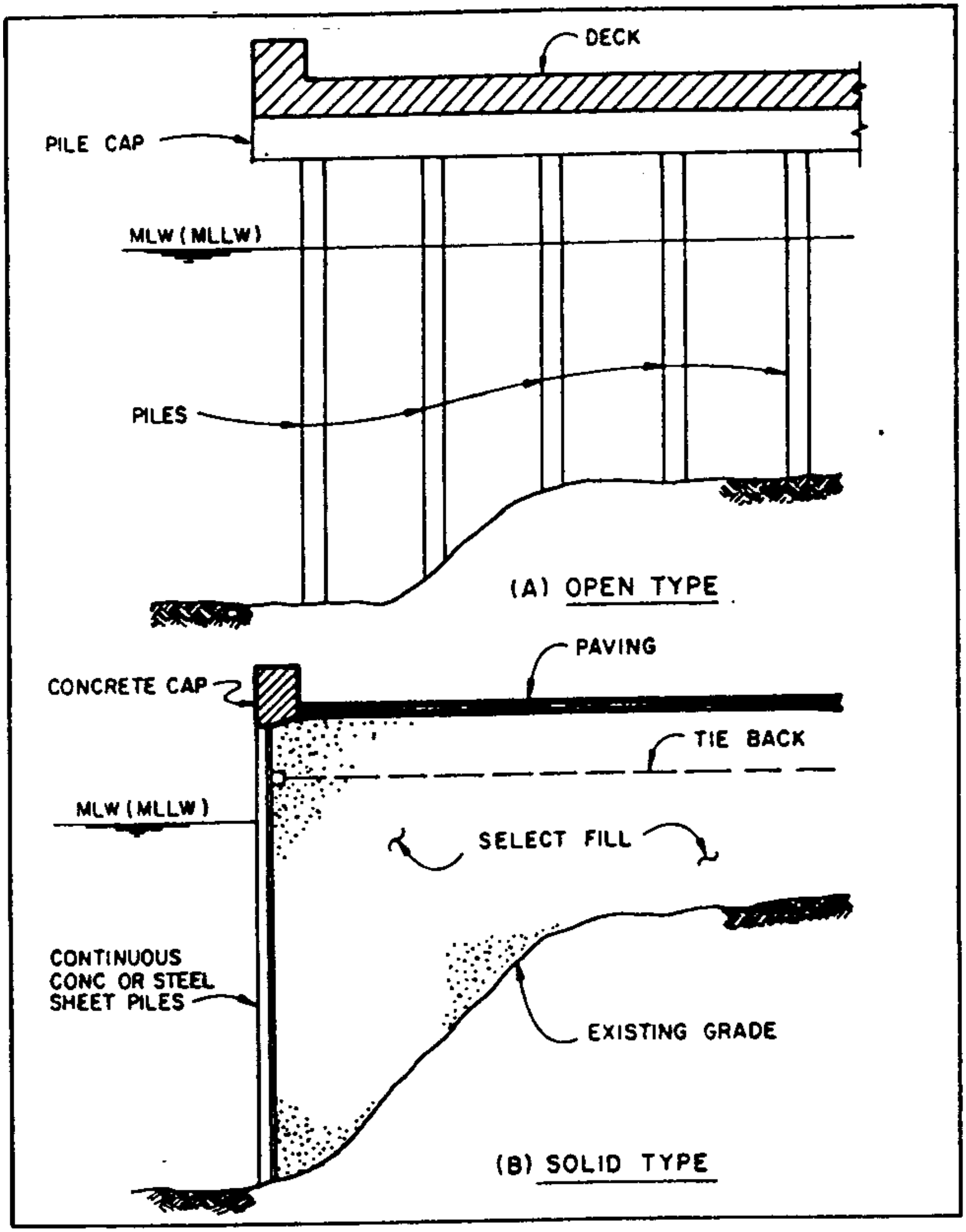

Figure 8
Open and Solid Types

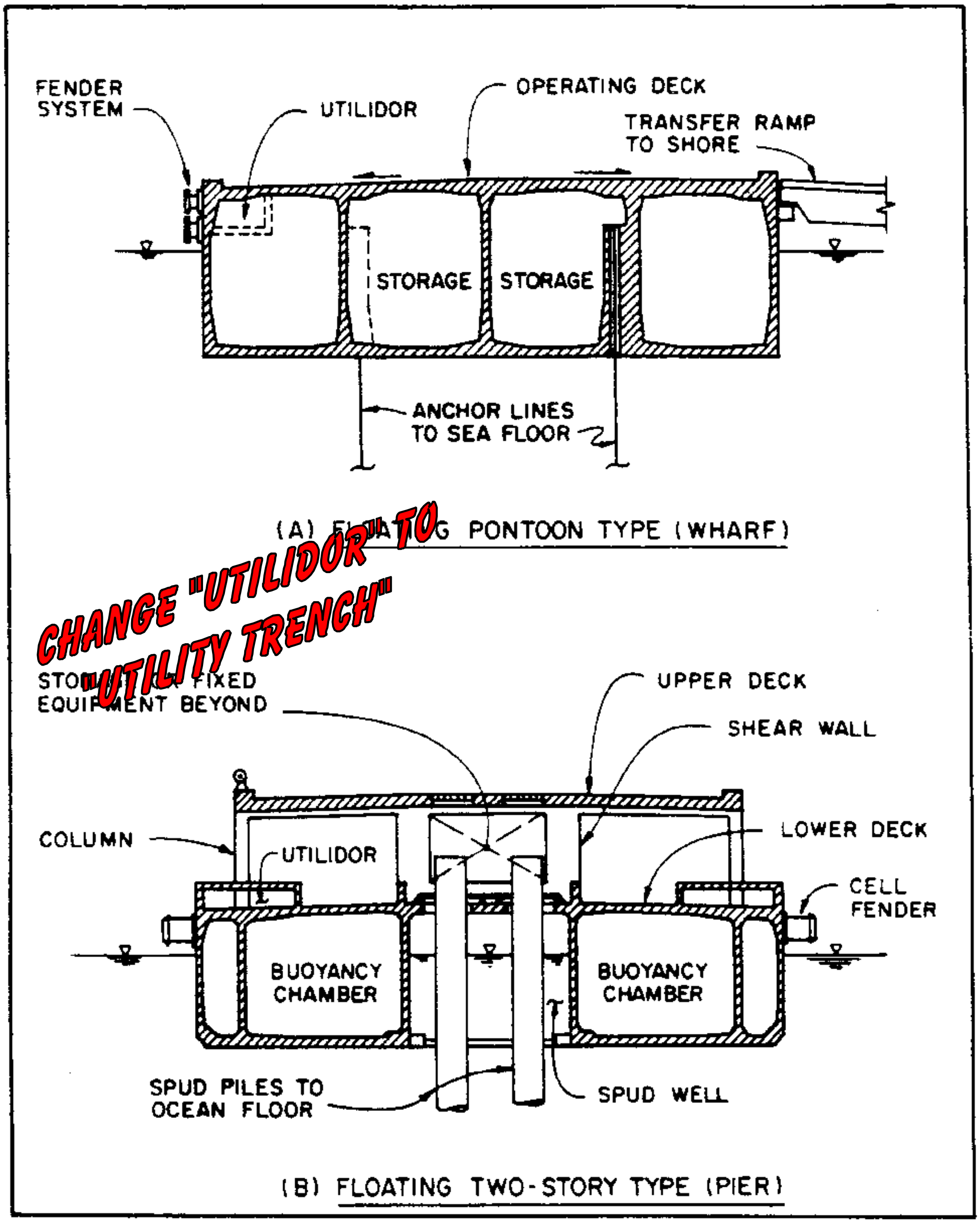

Figure 9
Floating Types

2.5.2 Combination of Types. Open and solid type can be combined along the length or across the width of piers and wharves where feasible and advantageous, as shown in Figure 10. However, it is not advisable to combine the floating type with the others.

2.5.3 Selection of Type. Several factors influence the selection of one structural type over the other. Each of these factors should be evaluated against the construction and operating costs of the facility before a final decision is made on the structural type. Greater emphasis should be placed on selecting the type that will withstand unexpected berthing forces and adverse meteorological and hydrological conditions, and will require little or no maintenance. **The geotechnical characteristics of a given site, and economic analysis of alternate structural types will often dictate structural requirements. For instance, in areas with poor near surface soils but with good end bearing for piles, an open pile supported structure with a shallow back bulkhead (or no bulkhead) will be most economical. Conversely, in areas with good near surface soils and poor pile bearing, a solid bulkhead may be more economical.**

2.5.3.1 Shoreline Preservation. The structural type is seriously influenced by aquatic and plant life existing along the shore of the planned facility. In environmentally sensitive areas such as river estuaries, the solid-type wharf, which would disturb or destroy a considerable length of shoreline, should not be considered. The open structural type, which would have the least impact on the shoreline, should be selected.

2.5.3.2 Bulkhead Line. When the facility extends outshore off an established bulkhead line, which is the limit beyond which continuous solid-type construction is not permitted, open-type construction should be used.

2.5.3.3 Tidal or Stream Prisms. Where it is required to minimize restrictions of a tidal or stream prism, which is the total amount of water flowing into a harbor or stream and out again during a tidal cycle, open-type construction should be used.

2.5.3.4 Littoral Drift. Along shores where littoral currents transporting sand, gravel, and silt are present, open-type construction should be used to mitigate shoreline erosion and accretion.

2.5.3.5 Ice. In general, open-type structures are vulnerable and should be carefully investigated at sites where heavy accumulations of sheet or drift ice occur. Also, when adfreezed ice thaws, large blocks of ice may slide down the piling, impacting on adjacent batter or plumb piles. Thus, the solid type may be preferable at such sites.

2.5.3.6 Earthquake. In areas of high seismic activity, construction utilizing sheet pile bulkheads or walls should be carefully considered because of the high lateral earth pressures that can develop on the sheet piling. When a pile-supported platform (with curtain wall) is used for a wharf structure in conjunction with hydraulic fill which is susceptible to liquefaction, a rock dike should be considered to resist the lateral forces that may be caused by liquefaction of the fill. The use of a filter fabric between the rock dike and granular fill should also be considered. In areas of extremely high seismic risk, and where tsunamis and seiches are anticipated, the floating type should be given serious consideration as it is less likely to be affected by or will suffer only minor damage from the seismic activity. **Reference Technical Report (TR) 2069, Design Criteria for Earthquake Hazard Mitigation of Navy Piers and Wharves; ASCE Monograph 12, Seismic Design Guidelines for Ports; and TR 2103, Seismic Criteria for California Marine Oil Terminals.** Both are available on NFESC's website, http://www.nfesc.navy.mil/pub_news/abstract.htm.

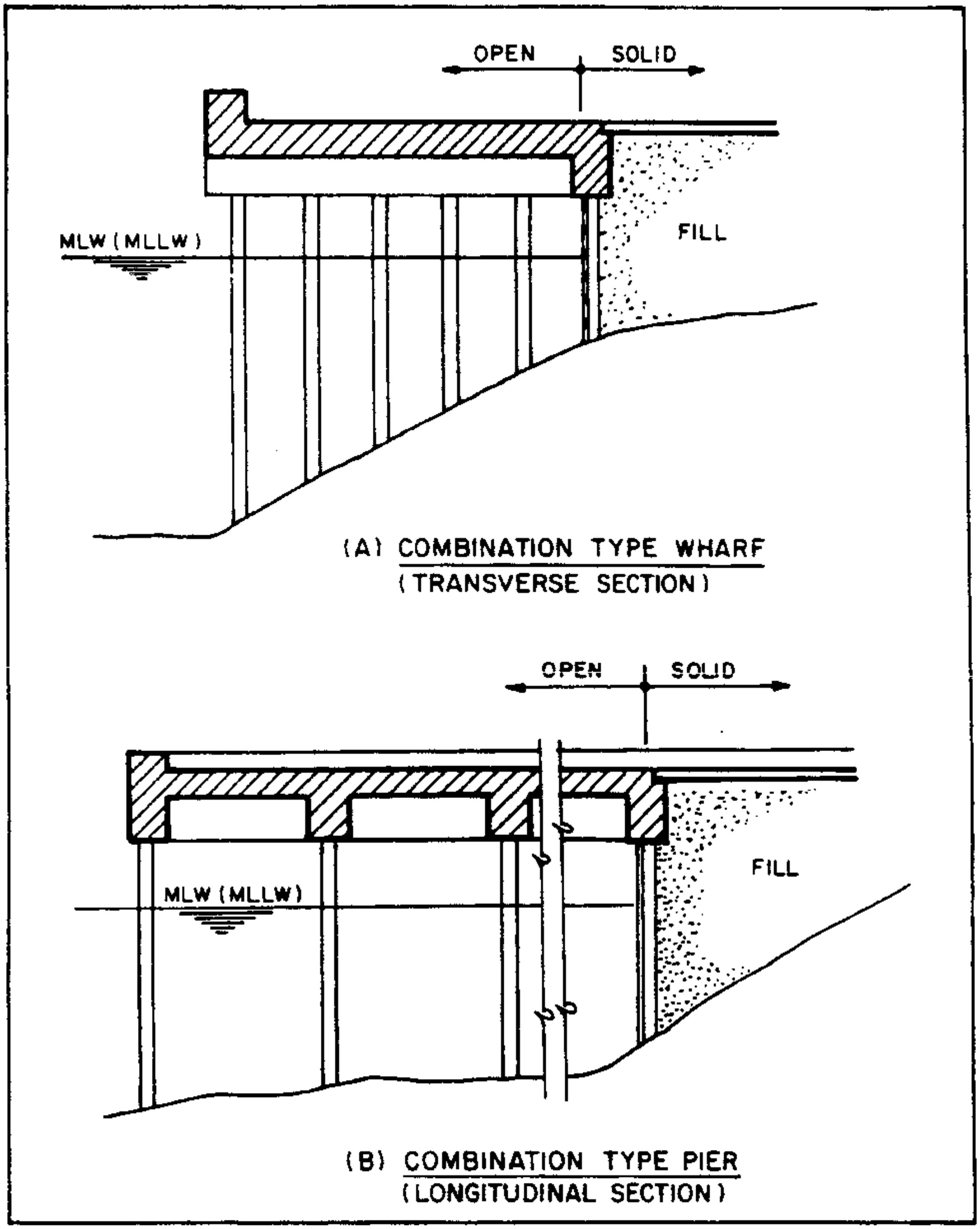

Figure 10
Combination Types

2.5.3.7 Water Depths. Open-type construction should be considered in all depths of water for facilities accommodating naval vessels, cargo vessels, and tankers expected to call at naval facilities. Depth limits for solid-type construction, utilizing sheet pile bulkheads, are imposed by the magnitude of the applied surcharge, subsurface conditions, and freeboard of the bulkhead above the low waterline. Generally, anchored sheet pile bulkheads may be considered in water depths up to 30 to 35 ft, where favorable soil conditions exist. When greater water depths are required at solid-type bulkhead structures, consideration should be given to the use of relieving platforms, bulkheads consisting of reinforced high-strength steel sheet piles, and cellular construction. **Combination pipe-z bulkhead may become economical for depths from 35 ft. to 60 ft. depending on soil conditions.** Where the water is very deep close to the shore and requires very long piles for open type, the floating type, which is unaffected by water depth, may be more economical. For additional design criteria, refer to Naval Facilities Engineering Command NAVFAC DM-25.04, Seawalls, Bulkheads and Quaywalls.

2.5.3.8 Subsurface Conditions. Generally, subsurface conditions do not limit the use of open-type construction. For almost all subsurface conditions, with the possible exception of rock close to the harbor bottom surface, suitable piles or caissons can be designed to carry the dead and live loads into the foundation material below. Where rock is close to the surface and pile seating may be difficult and costly, cellular construction should be considered. When open-type construction must be used in an area where rock is close to the surface, piles should be suitably socketed and anchored into the rock. Sheet piling, used for bulkheads or retaining walls in conjunction with platform wharf structures or combination piers, should be considered only when subsurface conditions indicate that suitable anchorage and restraint for the toe of the sheet piling can be achieved and where select material is available for backfill.

2.5.3.9 Fill Loss. When precast concrete and steel sheet pile bulkheads are used in pier and wharf construction, special care should be given to preventing fill leaching through the interlocks, causing subsidence of retained fill. A filter blanket or other method that could prevent or control fill leaching should be installed to reduce subsidence and consequent paving maintenance.

2.5.3.10 Advance Bases and Remote Areas. For advance bases, where rapidity of construction is required, open piers and wharves of the template or jackup barge type should be considered. Based on past experiences, it is estimated that a prefabricated template-type structure, 90 ft wide x 600 ft long, could be erected in about 21 days and a structure of the jack-up type could be erected in about 3 days. An advantage of the jack-up barge structure is that it can be moved and reused at other sites. For permanent facilities in remote areas, the floating type has advantages as the on-site construction is minimized.

2.5.3.11 Construction Time. Where an existing pier or wharf has to be replaced in active naval stations, the floating type has the advantage of minimizing the "downtime." Conventional construction may take too long where the loss of berths cannot be tolerated. The floating type in such situations may turn out to be the most expedient.

2.5.3.12 Ship Contact. In certain situations, where tugboats or camels are not available, sheet pile bulkheads located along the outshore face of pier and wharf structures may be less desirable than open-type construction because of the greater danger for contact between the sheet piling and the bulbous bow or sonar dome of a ship during berthing and unberthing maneuvers.

2.5.3.13 Track-Mounted Crane. Where a track-mounted crane is required for the pier or wharf, the solid type may not be suitable. The susceptibility of the solid filled type to settlement and movement will make it very difficult to maintain the close tolerance required for rail gage, elevation, and alignment. The surcharge loading on the sheet pile will also be considerable. For such cases, an independent pile-supported track should be utilized.

2.5.4 Construction. Several aspects of construction that are unique to each structural type should be considered as part of the facility planning phase.

2.5.4.1 Open. For open-type marginal wharves and landside ends of open piers, the following schemes should be considered for retaining upland fill:

a) Platform on Piles and a Curtain Wall at the Onshore Face. See Figure 11(A). The underwater slope should be as steep as possible, as limited by both constructional and geotechnical parameters, thus making the pile-supported platform narrow and more economical. In seismically active areas, where hydraulic fill susceptible to liquefaction is used for upland fill, a rock dike may be used instead of the granular fill dike to resist the lateral forces caused by liquefaction of the fill. The use of a filter fabric also should be considered at the hydraulic fill interface.

b) Platform on Pile and a Sheet Pile Bulkhead at the Inshore Face. See Figure 11(B). The sheet pile bulkhead permits a narrower platform. The cost tradeoff between platform width and bulkhead height should be investigated as the bulkhead may be found to cost as much or more than the pilesupported platform width it saves.

2.5.4.2 Solid. Retaining structures may be constructed by the following means:

a) Sheet Pile Bulkhead. See Figure 12(A). The bulkhead consists of a flexible wall formed of steel or concrete sheet piling with interlocking tongue and groove joints and a cap of steel or concrete construction. The bulkhead is restrained from outward movement by placing an anchorage system above the low water level. Many types of anchorage systems can be used. The most common types in use in the United States consist of anchor rods and deadman anchors. The latter could be made of concrete blocks, steel sheet piling, or A-frames of steel, concrete, or timber piles. ~~For further discussion, refer to NAVFAC DM-25.04.~~ In countries outside the United States,

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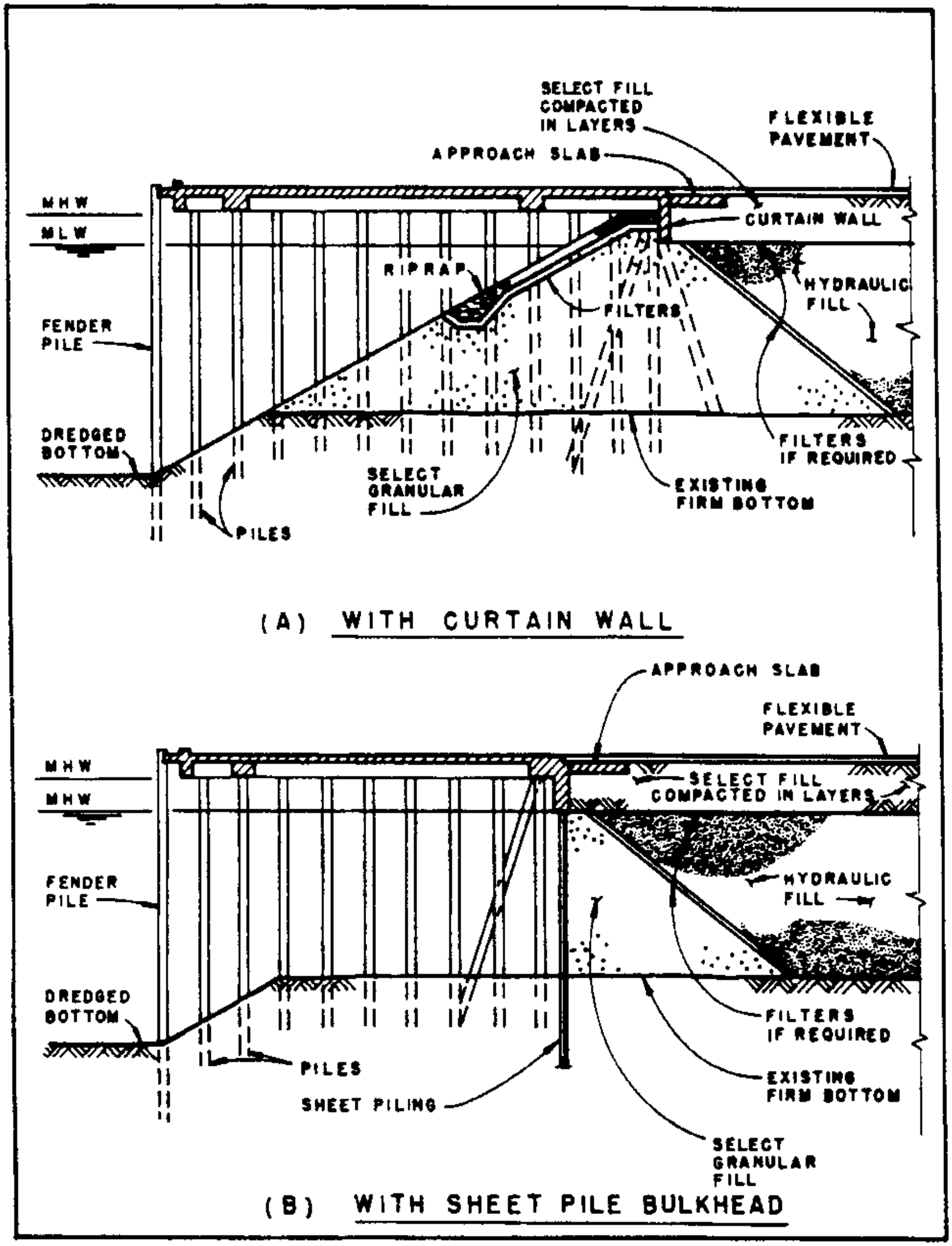

Figure 11
Open-Type Marginal Wharf Concepts

Open-Type Wharf Concept

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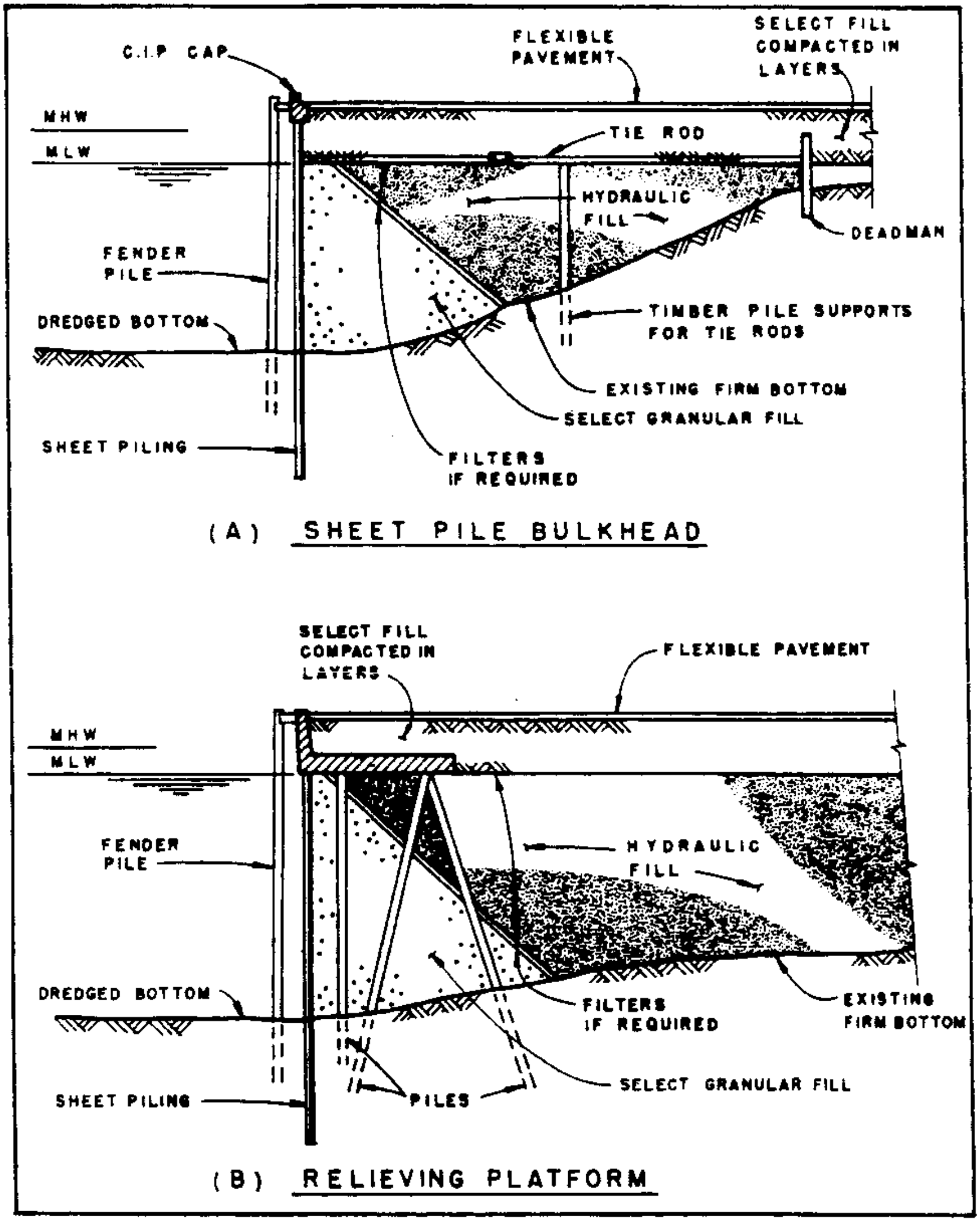

Figure 12
Solid-Type Marginal Wharf Concepts

Solid-Type Wharf Concept

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an anchorage system consisting of piles, attached near the top of the sheet pile bulkhead and extending at a ~~1-on-1 slope~~ batters up to 1 on 1 to embedment in firm material, is often used. Rock or earth anchors consisting of high-strength steel rods or steel prestressing cables are sometimes preferred in place of the anchor batter piles.

b) Sheet Pile Bulkhead and Relieving Platform. The relieving platform is used in conjunction with a sheet pile bulkhead to reduce the lateral load on the sheet piling created by heavy surcharges and earth pressures. As shown on Figure 12(B), lateral restraint is provided by the batter piles supporting the relieving platform. A variation of this type of construction is to use only vertical piles for the relieving platform and to furnish an independent anchorage system consisting of tie rods and deadman, similar to the types specified for sheet pile bulkheads.

c) Cellular Construction Consisting of Sheet Pile Cells. See Figure 13. For further discussion of sheet pile cells, see Section 4, paragraph 4.5.4, and Naval Facilities Engineering Command NAVFAC DM-7.02, Foundations and Earth Structures.

d) Reinforced Concrete Caisson. See Figure 14(A). In this type of construction, concrete caissons are cast in the dry, launched, and floated to the construction site where they are sunk on a prepared foundation. The caisson is filled with gravel or rock and a cast-in-place retaining wall is placed from the top of the caisson to the finished grade. This type of construction is prevalent in countries outside the United States.

e) Precast Concrete Blocks. See Figure 14(B). This form of solid wharf is a gravity-type wall made up of large precast concrete blocks resting on a prepared bed on the harbor bottom. A select fill of granular material is usually placed in the back of the wall to reduce lateral earth pressures. This type of construction is popular outside the United States.

2.5.4.3 Floating. Construction of the floating type usually requires a flood basin, graving dock, or drydock. The units are essentially constructed in the dry and floated out and transported (on their own or on barges) to the site. Availability of such a facility and transportation of the floating units through open ocean waters and restricted inland waters for deployment at the site are serious considerations. In this respect, the floating type has a significant advantage over others in that the bulk of construction activity can be shifted to other parts of the country where labor, economic, and environmental conditions are more favorable. Other concepts of construction such as barge-mounted construction and floating-form construction are described in Naval Civil Engineering Laboratory NCEL UG-0007, Advanced Pier Concepts, Users Guide.

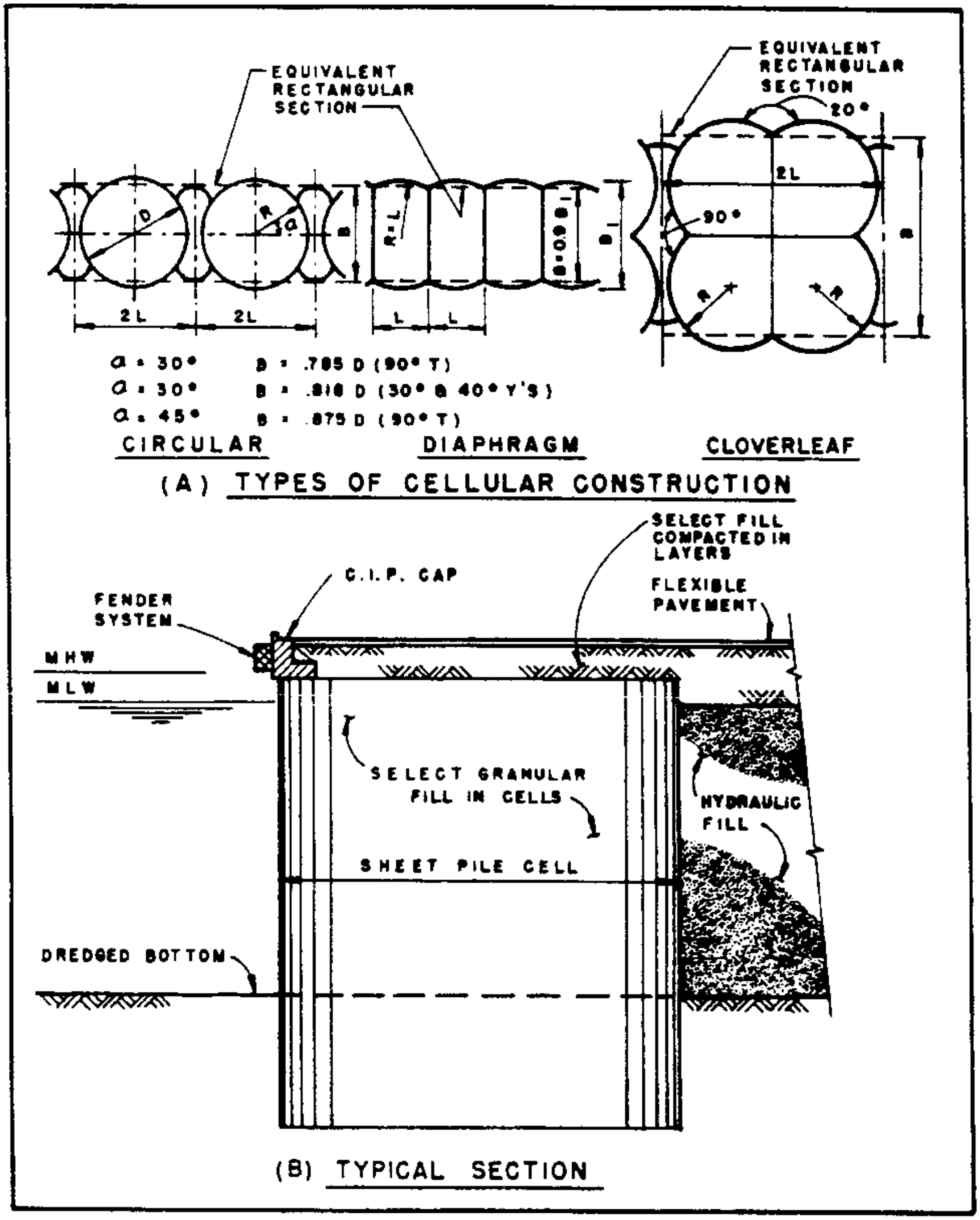

Figure 13
Solid Type, Cellular Construction

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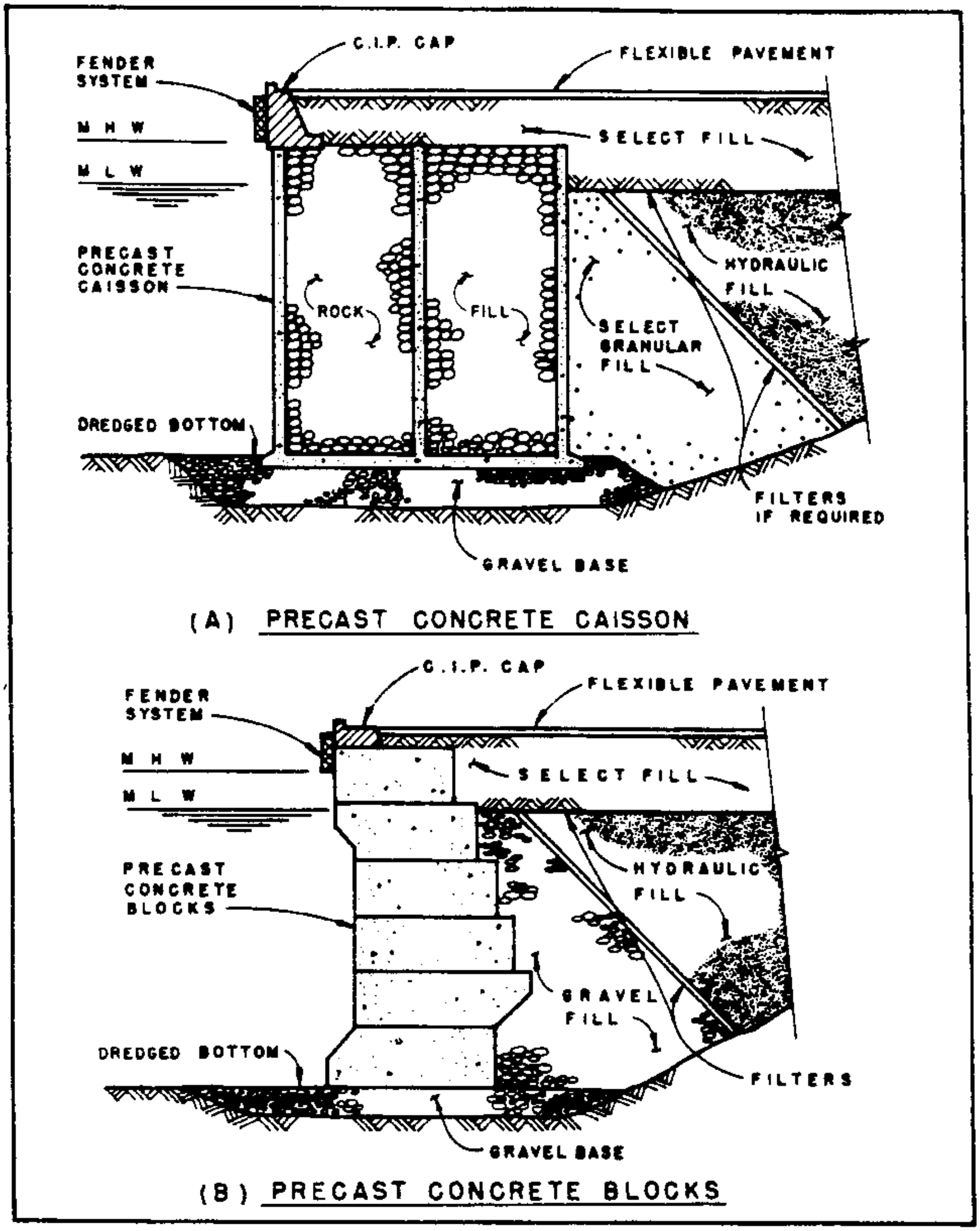

Figure 14
Solid Type, Caisson and Concrete Block Construction

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2.5.4.4 Hydraulic Fill. The soil drawn up by the suction head of a dredge, pumped with water through a pipe, and deposited in an area being filled or reclaimed is referred to as "hydraulic fill." At port and terminal facilities, where land is not available onshore and where dredging is required to provide adequate water depths for vessels at berths and approach channels, hydraulic fill is commonly used for land reclamation because of its availability and low cost. Hydraulic fill may be of good quality, consisting of granular materials, or may consist of plastic organic silt, which is considered poor quality. When hydraulic fill is used, the stability of the structure retaining the fill must be investigated, taking into consideration the effects of adjacent surcharge loadings in addition to the loadings from the fill. The placement of a select granular fill adjacent to the retaining structure, as shown on Figures 11 through 14, may be required if the hydraulic fill is of poor quality. Hydraulic fill is in a loose condition when placed. To avoid fill settlements due to loadings from other structures, stacked cargoes, and mobile equipment, stabilization of the fill may be required. In areas of seismic activity, the liquefaction of hydraulic fills should be investigated. Stability with regard to both settlements and liquefaction may be enhanced by methods such as deep densification or by use of sand drains. See ~~Naval Facilities Engineering Command NAVFAC DM-7.03~~MIL-HDBK 1007/3, Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction. Material other than hydraulic fill should be used when the cost of material obtained from onshore borrow areas is cheaper than the cost of material obtained from offshore borrow areas or where good quality fill material is required and is not available offshore. For additional design and construction consideration on fill construction, refer to Naval Facilities Engineering Command NAVFAC DM-7.01, Soil Mechanics.

Section 3. LOAD REQUIREMENTS

3.1 **General.** Load requirements for piers and wharves are provided herein. Where loading conditions exist that are not specifically identified herein, the designer should rely on accepted industry standards. However, in no case should other standards supercede the requirements provided by the MIL-HDBK.

3.~~1~~2 Dead Loads.

3.~~1~~2.1 General. The dead load consists of the weight of the entire structure, including all the permanent attachments such as mooring hardware, light poles, utility booms, brows, platforms, vaults, sheds, and service utility lines. A realistic assessment of all present and future attachments should be made and included. Design of fixed piers and wharves is usually controlled by live load and lateral load requirements. Hence, overestimation of dead loads generally will not adversely affect the cost of the structure. However, overestimation of dead loads will be unconservative for tension or uplift controlled design. Also, for floating piers and wharves, overestimating of dead loads will lead to significant cost penalties.

3.~~1~~2.2 Unit Weights. Actual and available construction material weights should be used for design. The following unit weights should be used for construction materials (unless lesser unit weights can be demonstrated by local experience):

Steel or cast steel	490 pcf
Cast iron	450 pcf
Aluminum alloys	175 pcf
Timber (untreated)	40 to 50 pcf
Timber (treated)	45 to 60 pcf
Concrete, reinforced (normal weight)	145 to 160 pcf
Concrete, reinforced (lightweight)	90 to 120 pcf
Compacted sand, earth, gravel, or ballast	150 pcf
Asphalt paving	135 to 150 pcf

3.~~2~~3 Vertical Live Loads.

3.~~2~~3.1 Uniform Loading. See Table 4 for recommended uniform loadings for piers and wharves. Impact is not applied when designing for uniform loads.

3.~~2~~3.2 Truck Loading. Truck loadings, as shown in Figure 15, are in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges. All piers and wharves should be designed for HS 20-44 wheel loads. In the design of slabs, beams, and pile caps, an impact factor of 15 percent should be applied. Structural elements below the pile caps need not be designed for impact. When truck loading is transferred through 1 ft 6 in. or more of crushed rock ballast and paving, and for filled construction, the impact forces need not be considered for design. Check with local activity for use of an overload vehicle such as weapons cradles, missile hauling vehicles, etc. Vehicles of this type may have significantly higher wheel and axial loads.

3.~~2~~3.3 Rail-Mounted Crane Loading.

3.~~2~~3.3.1 Portal Cranes. See Figure 16 for wheel loads of portal cranes and Table 4 for the rated capacities of portal cranes applicable to piers and wharves.

Table ~~4~~3
Vertical Live Loads for Pier and Wharf Decks

Classification	Uniform Loading (psf)	Mobile Crane (tons)	Rail-Mounted Crane (long tons)	Other Handling Equipment (tons)
Ammunition	600	90	--	20-lift truck
Berthing (carriers)	800	140	--	20-lift truck
Berthing (all others)	600	90	--	20-lift truck
Berthing (submarines)	600	90	--	20-lift truck
Fitting-out	800	140	50 Portal	20-lift truck
Repair	600	140	50 Portal	20-lift truck
Fueling	300	50	--	10-lift truck
Supply (general cargo)	750	140	--	20-lift truck
Supply (containers)	1,000	140	40 Container	20-lift truck 33-straddle carrier

3.~~2~~3.3.2 Container Cranes. See Figure 17 for wheel loads of container cranes and Table 4 for the rated capacities of container cranes applicable to piers and wharves. The data shown were derived from several operating cranes and can be used only for concept study and preliminary design. Cranes of varying capacities, configurations, and gages are available. Hence, more specific information should be obtained from crane manufacturers for final design. Recent tendency in container crane design has been to increase the gage and reach while maintaining the lift capacity between 40 and 50 tons. The increase in gage will lead to higher dead weight of the crane and may result in higher wheel loads.

3.~~2~~3.3.3 Wheel Load Uncertainty. Portal and container cranes are usually procured separately from the construction funds. The expected wheel loads may not be specified on the crane procurement documents. The actual wheel loads may therefore be higher than anticipated by the facility designer. The number and spacing of wheels are critical to the structural capacity of an existing facility and structural design of a new facility. Having established the required capacity and configuration of a crane, the designer of a pier or wharf should consult with the naval agency in charge of crane procurement and obtain wheel loads for which the supporting structure should be designed. In the absence of hard information, the loads presented in Figures 16 and 17 should be increased by 10 percent or more for the design of the facility.

3.~~2~~3.3.4 Impact. An impact factor of ~~20~~ 25 percent should be applied to the maximum listed wheel loads for the design of deck slab, crane girders, and pile caps. The impact factor is not applicable to the design of piles and other substructure elements~~. Also, for filled structures or where loads are distributed through paving and ballast (1 ft 6 in. or more), the impact factor is not applicable.~~

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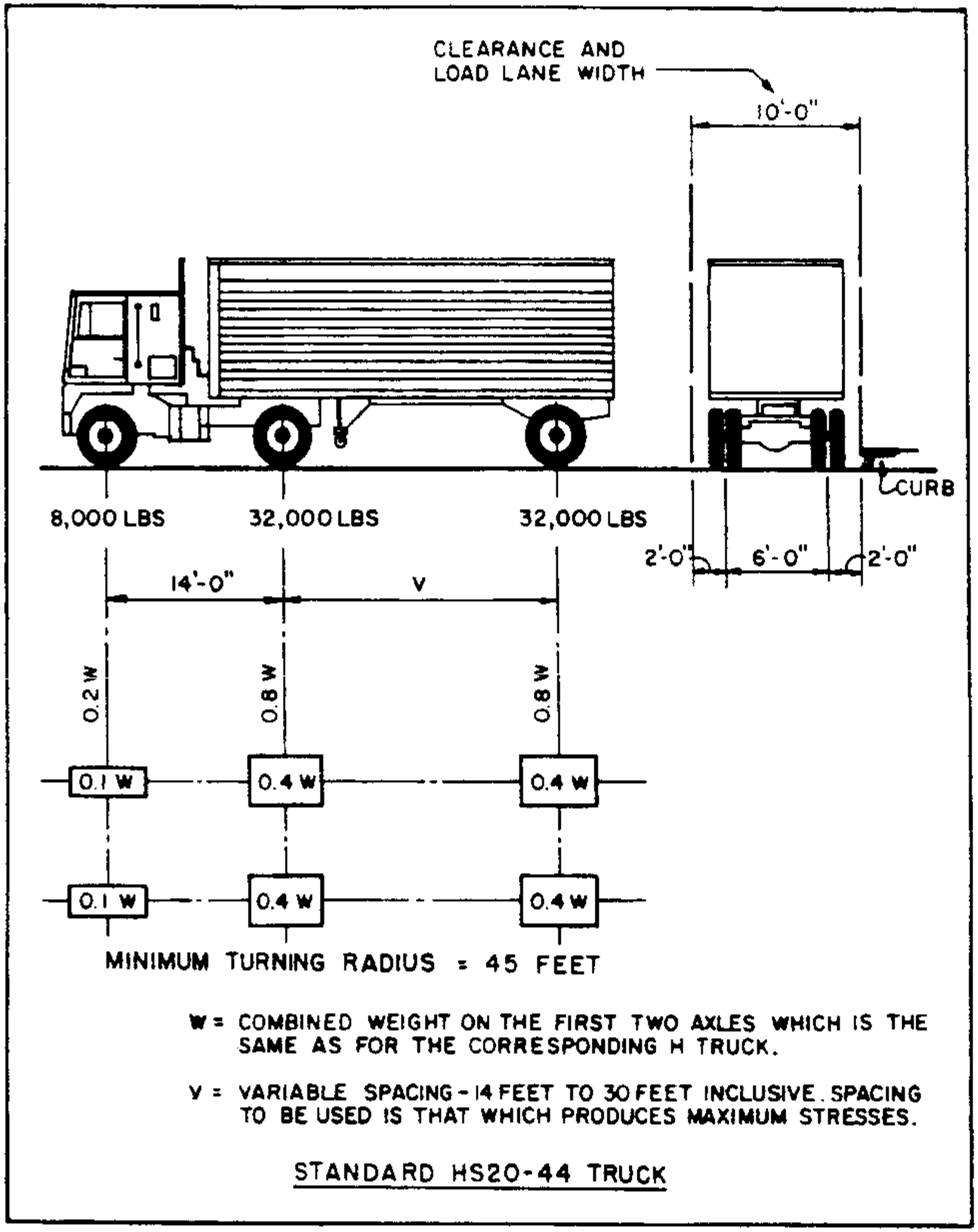

Figure 15
Truck Loading

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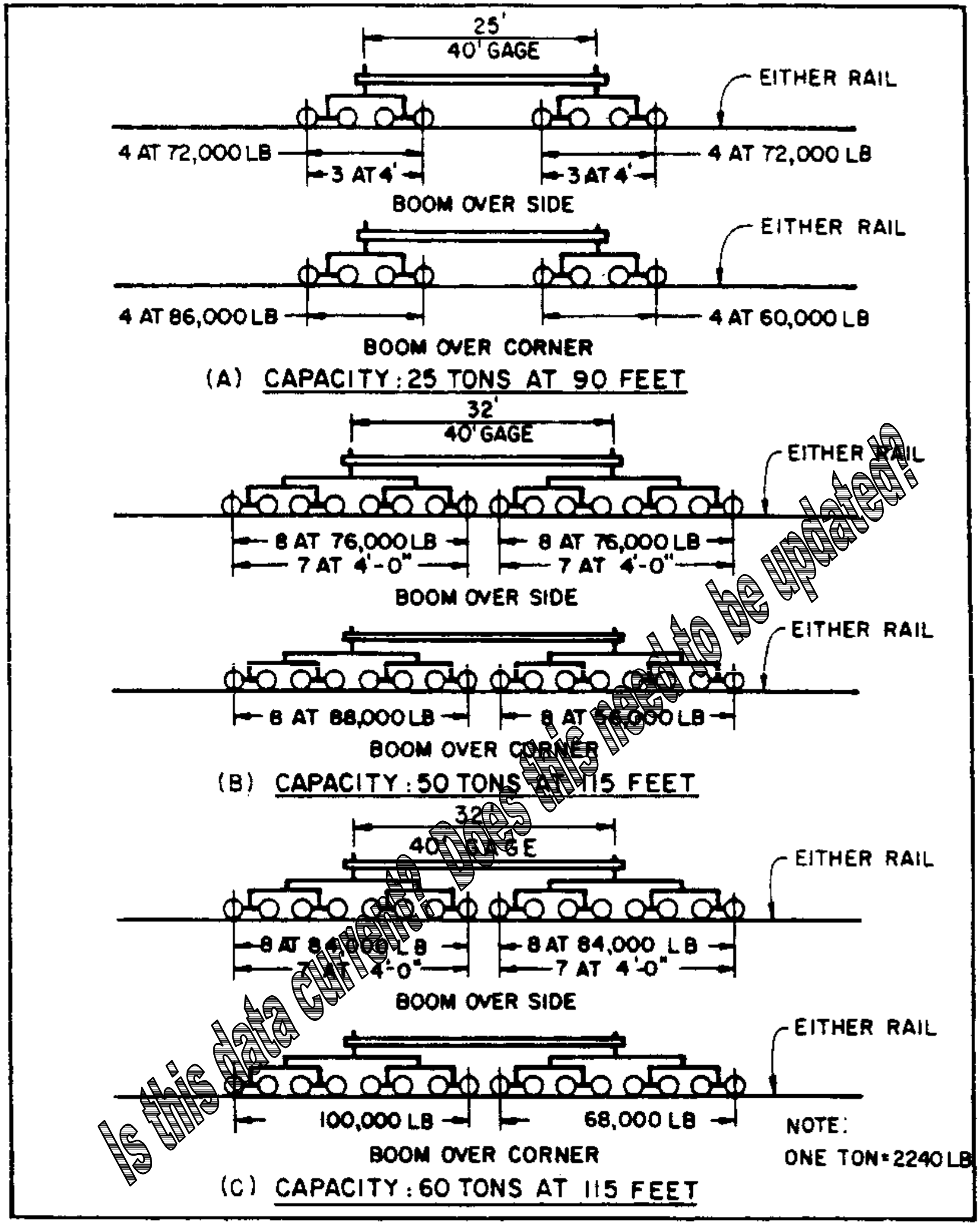

Figure 16
Wheel Loads for Portal Cranes

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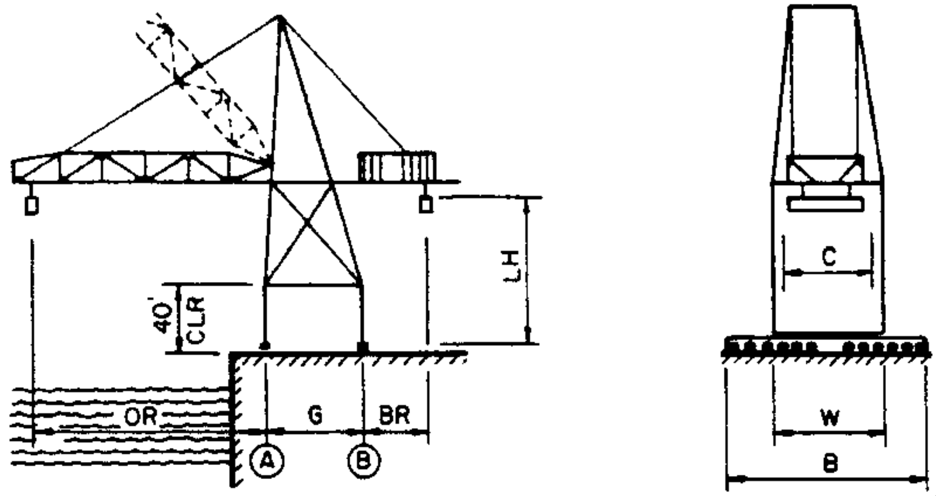
3.~~2~~3.4 Truck Crane Loadings. The deck design for open and floating structural types of piers and wharves is usually controlled by truck crane loading. However, the operational constraints imposed by under specifying truck crane loadings are severe. Consequently, care should be taken to specify realistic loading. Refer to Table 4 for designated truck cranes applicable to each functional type of pier and wharf. As a minimum the pier or wharvf should be designed for the designated truck crane, however, the design should confirm with the local activity that a crane larger than that designated is not available at the facility.

3.~~2~~3.4.1 Wheel Loads. See Figure 18 for wheel loads and Table 5 for outrigger float loads from 50-, 70-, 90-, 115-, and 140-ton capacity truck cranes. Tire contact area should be as defined by AASTHO. As a rule of thumb, ground pressures for "on rubber" lifts are about 10 percent higher than tire inflation pressure. Crane manufacturers recommend that the majority of lifts be made on outriggers. In addition, capacities for "on rubber" lifts are substantially less than for "on outrigger" lifts. Hence, loads for "on rubber" lifts are not listed. All piers and wharves and their approaches should be designed for the wheel loads from the designated truck crane. ~~Refer to Table 4 for designated truck cranes applicable to each functional type of pier and wharf.~~

Table ~~5~~4
Outrigger Float Loads for Mobile Cranes

Capacity (tons)	Radius (ft)	Boom Length (ft)	Boom Over Corner (lbs)	Boom Over Back (ea) (lbs)	Boom Over Side (ea) (lbs)
50	25 and less	40	112,000	98,000	95,000
	30	40	106,400	93,600	90,200
	40	40	94,100	83,200	80,300
	50	50	90,700	79,800	76,900
	60 and more	60	87,400	76,900	74,100
70	20 and less	40	151,000	124,000	113,500
	30	40	125,300	102,900	94,200
	40	40	108,700	89,300	81,700
	50 and more	50	102,000	83,700	76,600
90	20 and less	50	187,000	146,500	137,500
	30	50	160,800	127,500	119,600
	40	50	140,300	109,900	103,100
	50 and more	50	130,900	102,500	96,200
115	20 and less	50	241,500	198,000	186,000
	30	50	181,100	148,500	139,100
	40	50	154,600	126,800	119,100
	50 and more	50	144,900	118,800	111,600
140	25 and less	50	233,500	206,500	200,500
	30	50	221,800	198,200	192,500
	40	50	198,500	175,500	170,400
	50	50	181,000	161,100	156,400

Capacity (tons)	Radius (ft)	Boom Length (ft)	Boom Over Corner (lbs)	Boom Over Back (ea) (lbs)	Boom Over Side (ea) (lbs)
	60 and more	60	177,500	156,900	152,400



ITEM			CRANE CAPACITY	
			40' LONG TONS	50' LONG TONS
GAUGE - G			32' TO 100'	100'
OUTREACH - OR			115' TO 150'	125' TO 145'
BACK REACH - BR			35' TO 88'	30' TO 82'
WHEEL BASE - W			43' TO 50'	40' TO 51'
CONTAINER CLEARANCE - C			49' TO 66'	55'
OUT TO OUT OF BUMPERS - B			77' TO 89'	85' TO 89'
WHEEL SPACING (6 OR 8/LEG)			4' TO 5'	4.5' TO 5.5'
LIFT HEIGHT			80' TO 110'	89' TO 95'
MAXIMUM WHEEL LOAD IN KIPS (WITH 10 PSF WIND)	OPERATING	WATER SIDE (A)	87^k TO 150^k	99^k TO 126^k
		LAND SIDE (B)	64^k TO 120^k	65^k TO 100^k
	STOWED	WATER SIDE (A)	30^k TO 167^k	85^k TO 131^k
		LAND SIDE (B)	59^k TO 186^k	83^k TO 122^k

Is this data current? Does this need to be updated?

Figure 17
Wheel Loads for Container Cranes

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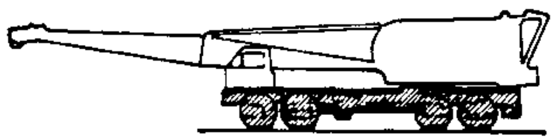
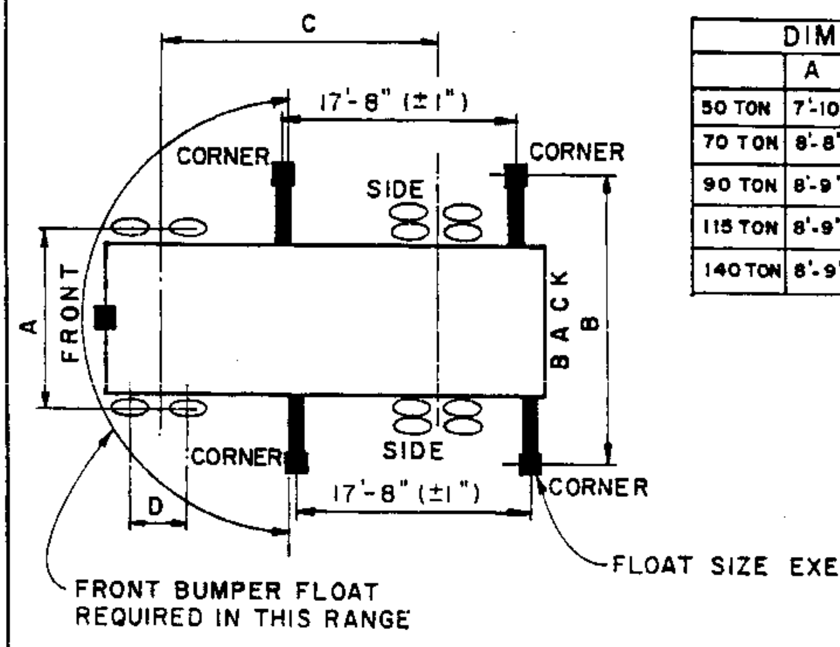


CRANE TRAVELING - BOOM OVER FRONT



DIMENSIONS	A	B	C	D	E
50 TON	7'-10"	18'-6"	18'-6"	4'-6"	2'-2"
70 TON	8'-8"	20'-6"	18'-8"	4'-6"	2'-2"
90 TON	8'-9"	20'-8"	19'-2"	5'-0"	2'-4"
115 TON	8'-9"	21'-8"	19'-2"	5'-0"	2'-6"
140 TON	8'-9"	21'-8"	19'-2"	5'-0"	2'-6"

CRANE TRAVELING - RUBBER TIRE WHEEL LOADS (LBS)

CRANE CAPACITY	TIRES NO.	TIRES SIZE	BOOM LENGTH (FT)	TOTAL WEIGHT (LBS)	BOOM OVER FRONT: EACH FRONT SINGLE TIRE	BOOM OVER FRONT: EACH REAR DUAL TIRE	BOOM OVER REAR: EACH FRONT SINGLE TIRE	BOOM OVER REAR: EACH REAR DUAL TIRE
50 TON	12	14.00-20	40	107,566	5,024	21,868	10,164	16,727
70 TON	12	14.00-20	40	114,580	4,683	23,963	12,780	15,865
90 TON	12	14.00-24	50	136,789	6,107	28,091	12,115	22,083
115 TON	12	14.00-24	50	163,190	4,521	36,277	15,518	25,280
140 TON	12	14.00-24	50	168,821	6,711	35,494	13,759	28,447

Figure 18
Wheel Loads for Truck Cranes

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3.~~2~~3.4.2 Outrigger Float Loads. Table 5 lists outrigger float loads for different capacity cranes. The maximum single float load from a boom over corner position and maximum concurrent pair of float loads from a boom over side and back positions are listed. Typically, the float loads are at the maximum when lifting the rated load at a short radius (20 to 25 ft) and should be used for design. However, for existing piers and wharves, the other listed loads may be used to analyze deck capacity. Outrigger float loads should be applied to an 1.5 foot by 1.5 foot area unless actual float size is known, in which case the actual float size should be used for analysis.

3.~~2~~3.4.3 Impact. An impact factor of 15 percent should be applied for all wheel loads when designing slab, beams, and pile caps. An impact factor of 25% should be applied to the maximum outrigger load or an impact factor of 30% applied to the rated lift capacity should be used which ever produces the greatest stress. The impact factor is not applicable to piles and other substructure elements. The impact factor need not be applied when designing for outrigger float loads and for design of filled structures, and where wheel loads are distributed through paving and ballast (1 ft 6 in. or more).

3.~~2~~3.5 Forklift and Straddle Carrier Loadings.

3.~~2~~3.5.1 Forklifts. See Figure 19 for wheel loads from forklifts and Table 4 for designated forklifts applicable to piers and wharves. Contact areas for wheel loads should be determined in accordance with AASTHO. For hard rubber wheels or other wheels not inflated, the wheel contact are should be assumed to be a point load.

3.~~2~~3.5.2 Straddle Carriers. See Figure 20 for wheel loads for a straddle carrier and Table 4 for straddle carriers applicable to piers and wharves. The straddle carrier shown is capable of lifting a loaded 20-ft container or a loaded 40-ft container. ~~For other types of straddle carriers, see MIL-HDBK-1025/3, Cargo Handling Facilities.~~

3.~~2~~3.5.3 Impact. An impact factor of 15 percent should be applied to the maximum wheel loads in the design of slabs, beams and pile caps. The impact factor is not applicable for the design of piles and other substructure elements, for filled structures, and where wheel loads are distributed through paving and ballast (1 ft 6 in. or more).

3.~~2~~3.6 Loading on Railroad Tracks. For freight car wheel loads, use a live load of 8000 lbs/ft of track corresponding to Cooper E-80 designation of the American Railway Engineering Association (AREA) Manual for Railway Engineering. In the design of slabs, girders, and pile caps, an impact factor of 20 percent should be applied. Impact is not applicable for the design of piles and filled structures, or where loads are distributed through paving and ballast (1 ft 6 in. or more).

3.~~2~~3.7 Buoyancy. Typically, piers and wharf decks are not kept low enough to be subjected to buoyant forces. However, portions of the structure, such as ~~utilidors~~utility trenches and vaults, may be low enough to be subject to buoyancy forces, which are essentially uplift forces applied at the rate of 64 pounds per square foot of plan area for every foot of submergence below water level.

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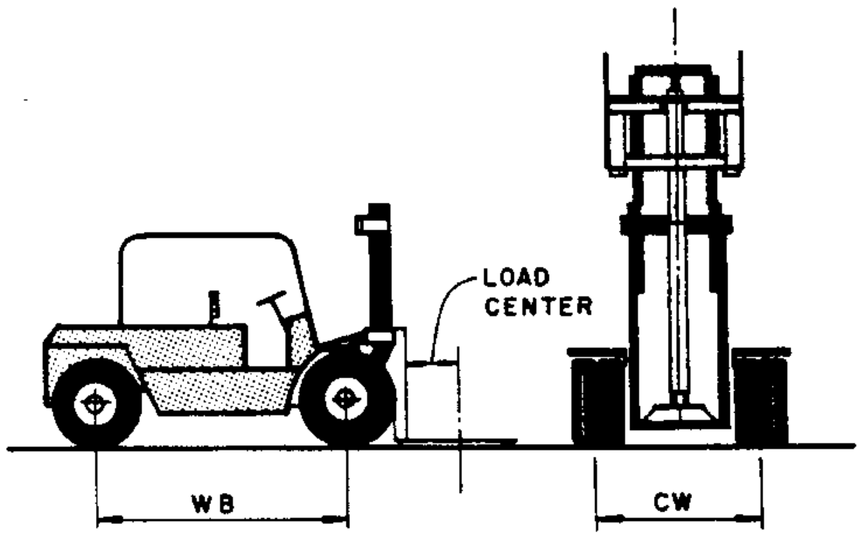

MAXIMUM LOAD (LBS.)	LOAD CENTER (IN)	SERVICE WEIGHT (LBS)	TURNING RADIUS (FT.-IN)	WHEEL-BASE (WB) (FT.-IN)	WHEEL SPAC. (CW) (FT-IN)	WHEEL LOADS (LOADED) EACH REAR SINGLE TIRE (LBS)	WHEEL LOADS (LOADED) EACH FRONT DUAL TIRE (LBS.)
10,000	24	15,000	12-10	8-3	6-3	2,000	10,500
12,000	24	16,000	12-10	8-3	6-3	2,500	11,500
15,000	24	19,000	13-0	8-9	6-4	2,500	14,500
16,000	24	19,500	13-0	8-9	6-4	2,500	15,250
20,000	24	20,000	14-0	9-6	6-4	2,500	17,500
24,000	24	25,300	14-9	10-0	6-4	2,500	22,150
30,000	24	34,000	15-3	10-9	6-6	3,000	29,000
40,000	36	63,000	14-11	10-0	8-0	2,500	49,000

Figure 19
Wheel Loads for Forklifts

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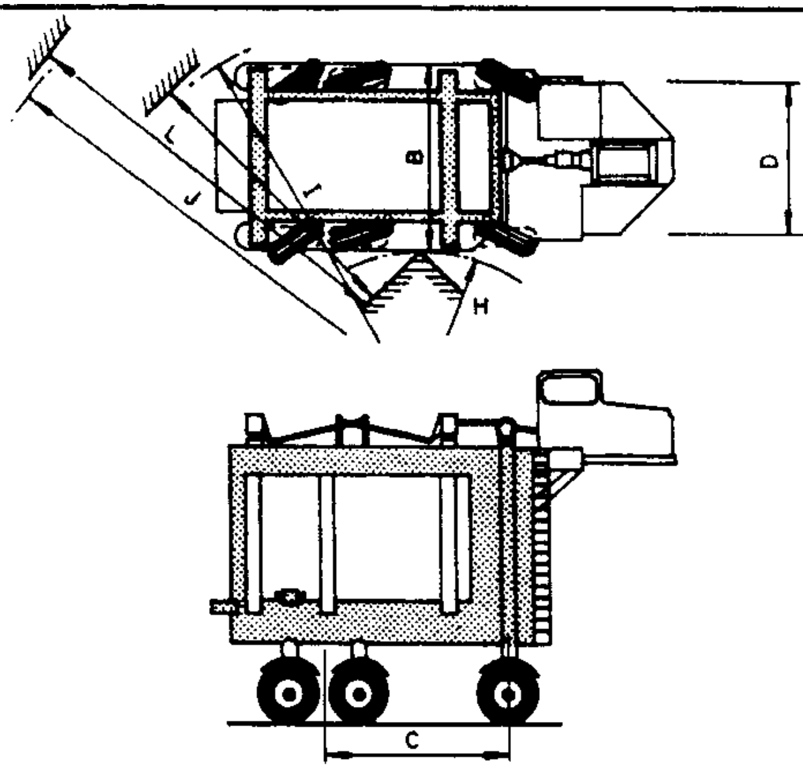

DEAD WEIGHT		67,000 LBS
SERVICE WEIGHT		89,000 LBS
WHEEL LOAD-EACH		26,000 LBS
OVERALL WIDTH	(B)	13'-4"
WHEELBASE	(C)	13'-4"
WHEEL CENTERS	(D)	11'-6"
INSIDE TURNING RADIUS	(H)	11'-3"
OUTSIDE TURNING (20ft. CONTAINER)	(I)	27'-10"
OUTSIDE TURNING (40ft. CONTAINER)	(J)	33'-4"
MINIMUM (20ft CONTAINER)	(K)	19'-4"
MINIMUM (40ft. CONTAINER)	(L)	25'-4"

Figure 20
Wheel Loads for Straddle Carriers

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3.3.8 **Wave Loading.** For piers and wharves exposed to waves which may produce significant lateral or hydrostatic forces, determine wave loading in accordance with the procedures defined in the Army Corps of Engineers, Shore Protections Manual.

3.~~2~~3.~~8~~9 Application of Loadings.

3.~~2~~3.~~8~~9.1 Concentrated Loads. Wheel loads and outrigger float loads from designated pneumatic-tired equipment, such as trucks, truck cranes, forklifts, and straddle carriers, should be applied at any point on a pier or wharf deck. The equipment may be oriented in any direction and the orientation causing the maximum forces on the structural members should be considered for design. For one-way flat slabs see NCEL R-935, **Lateral Load Distribution on One-Way Flat Slab.**

3.~~2~~3.~~8~~9.2 Simultaneous Loads. Generally, uniform and concentrated live loads should be applied in a logical manner. Designated uniform live loadings and concentrated live loading from pneumatic-tired equipment should not be applied simultaneously in the same area. However, uniform live load should be assumed between crane tracks (for 80 percent of gage). When railroad tracks are present between crane tracks, both track loads should be applied simultaneously. However, the maximum loads from each track need not be assumed.

3.~~2~~3.~~8~~9.3 Skip Loading. For determining the shear and bending moments in continuous members, the designated uniform loadings should be applied only on those spans which produce the maximum effect.

3.~~2~~3.~~8~~9.4 Critical Loadings. Concentrated loads from trucks, mobile cranes, forklifts, and straddle carriers, including mobile crane float loads, are generally critical for the design of short spans such as deck slabs and trench covers. Uniform loading, mobile crane float loading, rail-mounted crane loading, and railroad loading are generally critical for the design of beams, pile caps, and supporting piles.

3.~~3~~4 Horizontal Loads.

3.~~3~~4.1 Berthing Load. Ships are usually brought in with the assistance of two or more tugboats while berthing to a pier or wharf. Wind, current, wave, and tidal forces acting on the ship at the time of berthing ~~cause the ship to impact the pier or wharf~~ effect the approach velocity of the vessel as it nears the berth. To reduce the ~~berthing energy and~~ force transmitted to the structure, ~~usually~~ a fender system (fender units, fender piles, camels, and other energy-absorbing mechanisms) is used between the ship and structure to absorb the kinetic energy of the moving vessel. The magnitude and location of the actual force transmitted to the structure will depend on the type of structure, type of ship, approach velocity, approach angle, and fender system employed. Computer simulation models are available which provide a three-degree of freedom numerical model for time-domain simulation of impact forces on fendering systems.

These simulation models evaluate the motion of the berthing vessel in the time domain using the impulse-response method, which accounts for the appropriate hydrodynamic reaction forces that act on the vessel during berthing. The effectiveness of this method has been demonstrated in physical model test and field measurements. In the absence of reliable scale model test and/or computer simulation programs, the approach described in Section 5, paragraph 5.2, should be followed for calculation of berthing loads.

3.~~3~~4.2 Mooring Loads. Forces acting on a moored ship are produced by winds, currents, ~~and~~ waves, tides, and water level changes. The determination of mooring loads involves an evaluation of many variables including direction and magnitude of winds, currents, and waves; exposure of the berth and orientation of the vessel; number and spacing of mooring points such as bollards and cleats; layout of mooring lines; and elasticity of mooring lines and the load condition of the vessel (light, ballasted, or loaded). In sheltered waters where piers and wharves are usually constructed, wind generated wave forces are not significant and may be ignored. However, at piers and wharves where vessels are aligned adjacent to navigable channels, surge from passing ships may need to be considered. The current and wind load components of the moored ship are usually significant and should be calculated separately. ~~Computer simulation programs and model tests have been employed in an attempt to develop a rational approach for the calculation of mooring forces but, in view of the complexities involved in analyzing all the variables and combinations thereof, criteria for determination of mooring forces are generally established based on judgment and experience with similar facilities.~~ Forces due to winds, currents, and waves acting on moored ships should be estimated in accordance with the methods discussed in ~~Naval Facilities Engineering Command NAVFAC DM-26.06, Mooring Design Physical and Empirical Data~~ MIL-HDBK 1026/4, Mooring Design. ~~Alternatively, or when deemed necessary, mooring~~ Mooring forces may be approximated by the methods discussed below. The mooring forces so determined may be more conservative than those estimated by the methods discussed in ~~NAVFAC DM-26.06 but, in view of the indeterminate nature of mooring force analyses and the fact that wind and current pressures are very sensitive to small variations in velocity (varying as the square of the velocity), the results obtained are considered to be within the range of accuracy that can reasonably be expected~~ MIL-HDBK 1026/4 and therefore should be used for preliminary design, small vessels, low design wind speeds, or when a conservative design approach does not result in significant cost penalties.

3.~~3~~4.2.1 Mooring Arrangements. Ships are moored to piers and wharves by securing ship mooring lines to deck fittings located on the mooring structure. Mooring forces are transmitted to the structure when the ship bears on the structure or by tension in the mooring lines. For approximating forces in mooring lines secured to deck fittings, consider the schematic arrangements shown on Figure 21. The type of mooring arrangement selected and number of lines used will depend upon the size of the ship, site conditions, tidal fluctuations, and the preference of the ship's master. The layout shown on Figure 21(A) is typical but many variations are possible, as shown on Figures 21(B) and 21(C). As shown on Figure 21(A), bow and stern lines are generally placed at angles of about 45 deg. horizontally. Spring lines are generally at angles of about 5 deg. horizontally and breast lines are almost perpendicular to the longitudinal axis of the vessel. When breast lines are omitted, as shown on Figures 21(B) and 21(C), the loads normally carried by breast lines are carried by the bow and stern lines. Vertically, mooring lines preferably should not be placed steeper than 30 deg. from horizontal. When ships are moored without separators and for certain types of ships such as amphibious ships, the vertical angles may be steeper. See Figure 21(D). The latter criteria should be considered when establishing deck elevations. ~~Consideration should also be given to the fact~~ It is recommended that mooring lines should be at least 100 ft in length in order to minimize the possibility of having lines part due to ship movements. Types and strengths of mooring lines are discussed in ~~NAVFAC DM-26.06~~ MIL-HDBK 1026/4. Design and spacing of deck fittings are discussed in Section 4, paragraph 4.7.4. Whatever assumptions are made by

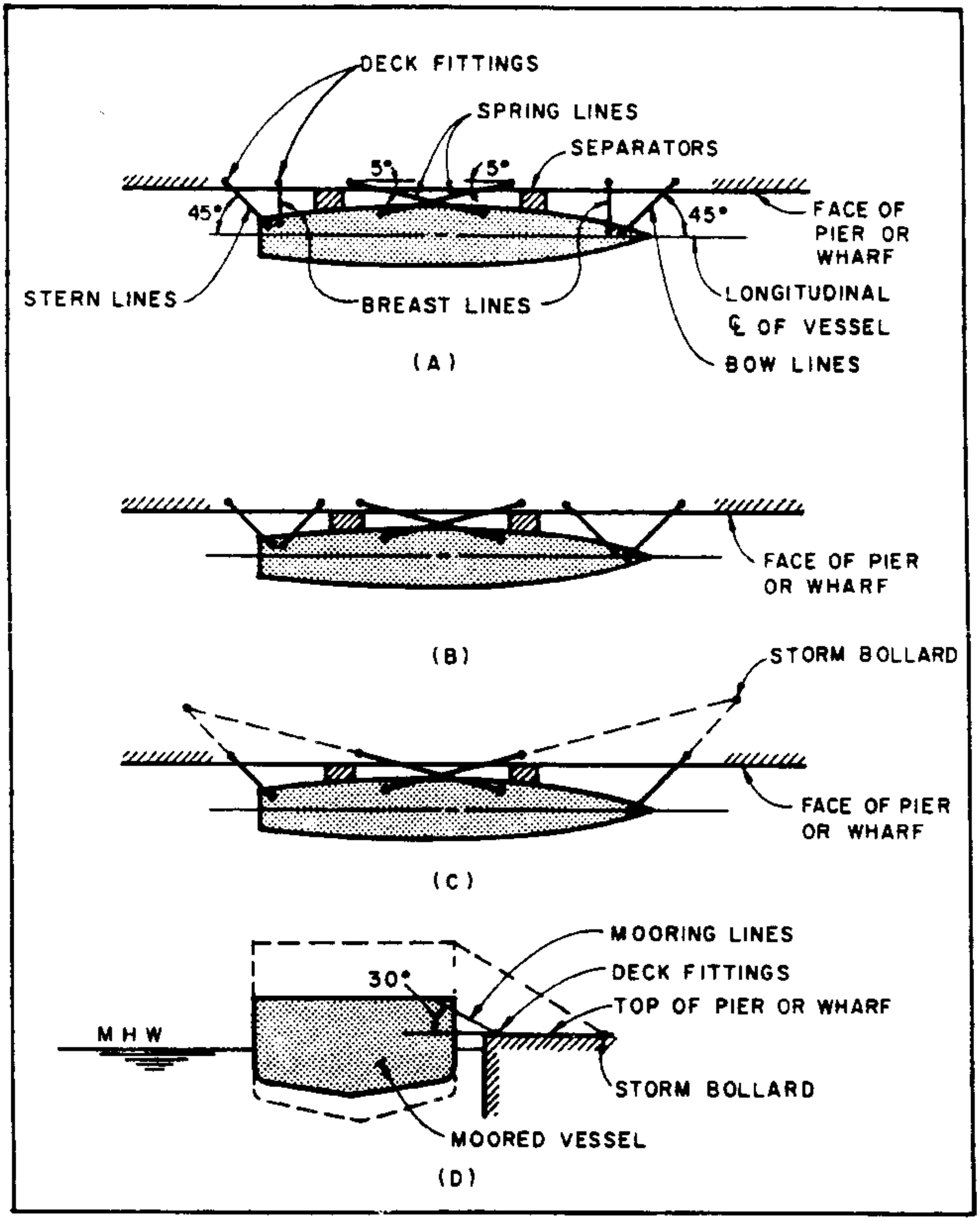

Figure 21
Mooring Arrangements

the designer, the ship will use a different arrangement of mooring lines and separators. Hence, it is not unreasonable to assume a pattern of mooring lines least favorable to the structure.

3.~~3~~4.2.2 Ship Motions. A moored ship will develop motions, as shown on Figure 22(A), due to winds, currents, tides, and waves. The type of motion will depend upon the magnitude and direction of the external forces acting on the ship, individually or in combination. The fender system, mooring arrangement, and type of mooring lines should be selected to minimize the magnitude of these ship motions and also to minimize the resultant forces transmitted to the mooring structure.

3.~~3~~4.2.3 Limiting Conditions. To minimize the effects of the forces acting on a moored vessel, piers and wharves are generally located in sheltered waters or are oriented so that a moored vessel is headed into the prevailing winds, currents, or waves. In some locations, conformance to criteria cannot be met because the siting of a structure is predetermined by the configuration of existing facilities. When designing structures for mooring forces, ~~consideration should be given to the fact that it is not practical or economical to design for the maximum combination of winds, currents, or waves that exist at a given site. Usually limiting conditions for keeping a ship at berth are observed, because it is expected that a ship will take on ballast to reduce wind presentment or leave the berth and put to sea. Before a final determination is made, the limiting wind velocity should be reviewed with the specific service requirements of the individual installation considering pertinent factors such as site conditions, operational requirements, vessel capabilities, and feasibility and economy of construction. In any case, the minimum limiting wind velocity should be taken as 70 miles per hour for the design of the structure and for computing mooring forces on the fendering system. The maximum wind velocities (highest average of wind velocities with 30-second duration) as recommended by NAVFAC DM-26.06 should be used for design of mooring hardware.~~the limiting conditions should be determined in accordance with MIL-HDBK 1026/4, Section 3, for the "Mooring Service Types." The mooring service types define the operational function that the facility is intended to serve and the limiting conditions that are required for that function. Mooring facilities should be designed using the site specific criteria provided in MIL-HDBK 1026/4, which gives design criteria in terms of environmental design return intervals and in terms of probability of exceedence for 1 year of service life. Mooring Service Types are as follows:

Type I - This type covers moorings that are used for up to 1 month by a vessel that will leave prior to an approaching tropical hurricane, typhoon, or flood. Moorings include ammunition, fueling, and deperming facilities, as well as ports of call.

Type II - This type covers moorings that are used for 1 month or more by a vessel that will leave prior to an approaching tropical hurricane, typhoon, or flood. Moorings include general purpose berthing facilities.

Type III - This type covers moorings that are used for up to 2 years by a vessel that will not leave prior to an approaching tropical hurricane, typhoon, or flood. Moorings include fitting-out, repair, drydocking, and overhaul berthing facilities. Ships experience this service approximately every 5 years. Facilities providing this service are nearly always occupied.

Type IV - This type covers moorings that are used for 2 years or more by a vessel that will not leave in case of a hurricane, typhoon, or flood. Moorings include inactive, drydock, ship museum, and training facilities.

a) ~~Design wind velocities higher than 70 miles per hour should be considered in a situation where a moored ship cannot be readied to leave the berth and put to sea prior to the onset of a storm, or because the~~At Type III and IV moorings or where a ship is moored at a pier or wharf which is located in an area of rapidly developing storms and sufficient advance warning is not available, ~~. This problem is particularly critical to large ships such as carriers which may be in a "cold iron" status and will need several days to prepare to leave a berth. Where wind speeds higher than 70 miles per hour can be expected more frequently,~~ consideration should be given to locating high-capacity (200 tons or more) "storm" bollards along the centerline of the pier or inboard edge of the wharf, where the ship can be tied up to a more favorable line angle and higher capacity mooring hardware.

b) Long period waves or swells, generated over long fetch distances, are considered hazardous for all ship classes and when data indicate that swells may occur at a site, special investigations and studies are required to determine limiting conditions. Beam currents acting broadside to a moored ship, with velocities greater than 2 knots, should be avoided, where feasible, because of the large forces created. Bow and stern currents, parallel to the longitudinal axis of a ship, can be tolerated up to velocities of about 5 knots.

3.~~3~~4.2.4 ~~Critical~~ Approximate Loadings. In the determination of mooring forces due to winds, current, and waves, the following factors should be considered:

a) The structure should be capable of holding any one ship at berth for the maximum wind velocity in a multiple berth pier. Also, in a dedicated single-berth pier where the ship can be tied up only to one pier, the maximum wind velocity should be used.

b) Forces acting parallel to a moored vessel on the bow or stern, at angles of attack of 0 or 180 deg., produce maximum loads in spring lines. (See Figure 23.) When one ship is at berth, the yawing moment, approximately equal to the total longitudinal force multiplied by half the ship's beam plus the width of camels and/or fendering devices, need not be considered but, when several ships are berthed in nests, the effect on the yawing moment should be investigated.

c) Forces acting perpendicular to the longitudinal axis of a moored ship, at angles of attack of 90 deg. or 270 deg., generally produce the maximum total forces on the ship. Referring to Figure 23(A), when the angle of attack is 90 deg., the external forces will push the ship onto the structure and the mooring loads will be transmitted to the structure along the parallel body of the ship in contact with the fender system or along the contact lengths of separators placed between the ship and the fender system of the structure. The parallel body of a ship refers to the midbody of the ship along whose length the hull cross section is constant and the sides are vertical. Generally, combatant ships, designed for speed, have shorter parallel bodies and more rakish forebodies and afterbodies than slower cargo ships with longer parallel bodies and blunter ends. When the angle of attack is 270 deg., the ship will be pushed off the structure and the resultant loads will be transmitted to the structure by tension in the mooring lines. The total force acting on the ship may be assumed to be divided equally between the fore and aft breast lines or, in the absence of breast lines, between the mooring lines, fore and aft, absorbing the force.

d) Quartering forces are those forces which act at angles of attack approximately equal to 45 deg., 135 deg., 225 deg., and 315 deg. (See Figure 23.) The yawing moments produced are maximum under these conditions and, when forces tend to push the ship off the structure, produce maximum loads in the breast lines. Forces due to quartering winds or currents may be approximated by assuming that the total lateral force is equal to 0.75 times F and the yawing moment is equal to 0.09 times F times L where F is the total force acting broadside to the ship (at right angles to the longitudinal centerline of the ship) and L is the length of the ship. The maximum load in the fore and aft breast lines is approximately equal to one half the total lateral force plus the force obtained by dividing the yawing moment by the distance between breast lines, which is the lever arm of the resisting moment. The force due to the yawing moment is additive or subtractive, depending upon the direction of the quartering winds or currents. Wind and current forces on separators may be approximated in the same manner except that L is the distance between centerlines of separators.

e) Wind and current directions within a sector described by angles of 20 deg., each side of the longitudinal axis of a moored ship, may be considered as parallel to the ship. Similarly, wind and current directions within the sector described by angles of 20 deg., each side of a line perpendicular to the longitudinal axis of a ship, may be considered as perpendicular or broadside to the ship. Directions between the sectors described may be considered as quartering winds and currents.

f) Prevailing winds and currents are not necessarily the strongest. Winds and currents of greater intensities, but which occur less frequently, may come from other directions. Accordingly, when determining mooring loads, consideration should be given to winds and currents acting in the direction which produces the maximum loads.

g) When ships are berthed on both sides of a pier, the wind load on the ship in the leeward berth may be approximated to be 50 percent of the wind load on the windward vessel.

3.~~3~~4.3 Wind Loads on Structures. Wind forces on the pier or wharf structure, sheds, container and portal cranes, and other stationary facilities should be estimated from the criteria ~~discussed in Naval Facilities Engineering Command NAVFAC DM-2.02, Structural Engineering - Loads. The minimum force should be equivalent to a wind velocity of 80 mph.~~provided in ASCE 7, Minimum Design Loads for Buildings and Other Structures, latest version, and the International Building Code (IBC) 2000.

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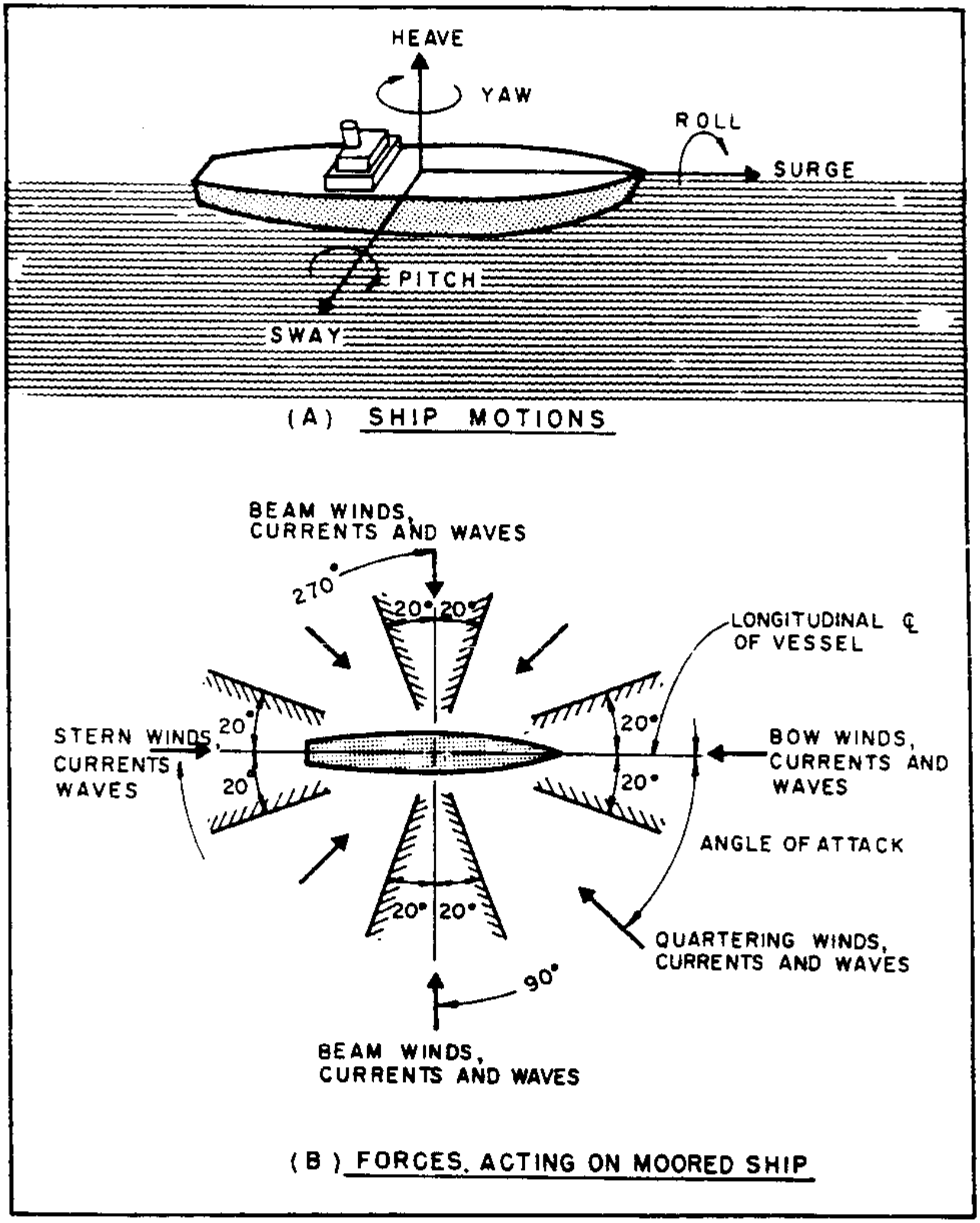

Figure 22
Ship Motions and Forces Acting on Ship

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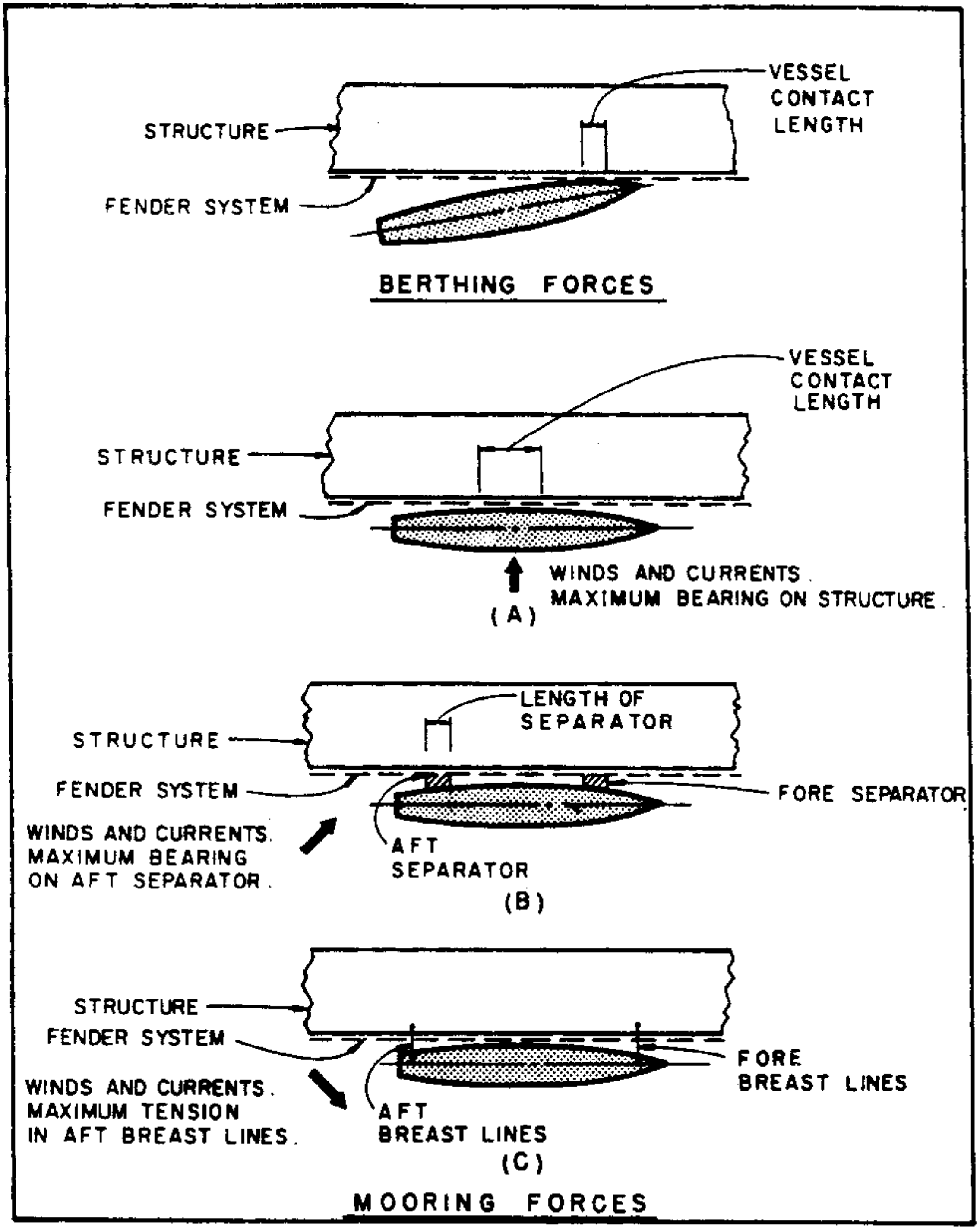


Figure 23
Distribution of Berthing and Mooring Forces to Structure

3.~~3~~4.4 Earthquake Loads.

3.~~3~~4.4.1 Criteria. All piers and wharves located in seismically active areas should be proportioned to resist earthquake forces in accordance with the requirements of the 1996 AASHTO Standard Specifications for Highway Bridges; and using the modifications to AASHTO provided in TR-2069-SHR, Design Criteria for Earthquake Hazard Mitigation of Navy Piers and Wharves. Additional guidance may be found in TR-2103-SHR, Seismic Criteria for California Marine Oil Terminal (Volumes 1 & 2); and American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering, Monograph 12, 1998, Seismic Guidelines for Ports. ~~Dynamic analysis of the structure for a locally accepted site-specific response spectrum may be used as an alternative. For open piers and wharves, the approach recommended by Tudor/PMB Consulting Engineers in Seismic Design of Piers (a NAVFAC-sponsored study) may also be used as an alternative.~~

3.4.4.2 Performance Goal. The pier or wharf structure shall be designed to resist the loading produced by:

a) A Level 1 earthquake with a 50 percent probability of exceedance in 50 years exposure. This is a nominal 475-year return period event ground motion. The structure shall resist this level of force without significant structural damage.

b) A Level 2 earthquake with a 10 percent probability of exceedance in 50 years exposure. This is a nominal 950-year return period event. With this event, the structure is allowed a measure of controlled inelastic behavior that will require repair, but will preclude total collapse and life safety is maintained.

c) An earthquake with a 10 percent probability of exceedance in 100 years exposure for piers and wharves that are part of fueling systems. The structure shall preclude the release of hazardous and polluting materials.

The determination of the design earthquake shall be performed using techniques described in NFESC TR-2016-SHR, Procedures for Computing Site Seismicity.

~~The AASHTO method considers the interrelationship of factors such as the location of the site relative to active faults, the effect of the overlying soil on the earthquake motion, and the dynamic response characteristics of the structure. When applying the AASHTO method to the design of piers and wharves, the following should be considered:~~

~~a) The weight of the structure should include the total dead load and a percentage of the design live load. The percentage of live load to be used should be 10 percent for all the functional types. For supply piers and wharves, 20 percent or higher should be used. For infrequently used facilities where there is less likelihood of any live load on the deck, this percentage of live load to be included may be omitted.~~

~~b) The depth of overburden to "rock-like" material should be determined from borings or other geological data.~~

~~c) The maximum expected acceleration expressed as a percentage of "g" at bedrock, at the site, should be estimated. This earthquake coefficient is approximated by evaluating past earthquake history, plotting active faults, assigning probable earthquake magnitudes to the faults, relating the earthquake magnitudes to rock acceleration levels and, finally, determining the attenuation of rock acceleration levels at points distant from the faults. If data, based on the procedure outlined above, are not available, peak rock acceleration levels assigned to seismic zones delineated on the seismic risk map of the United States, as outlined in the AASHTO criteria, may be used. These rock acceleration levels are the maximum expected values for the various seismic risk zones and, in certain cases, may result in seismic forces larger than necessary because of distance from active faults.~~

~~d) In determining the seismic force, the period of vibration of the structure must first be calculated.~~

~~e) The framing factor should be taken as 1.0 for framing using both plumb and batter piles and 0.8 for framing using only plumb piles.~~

~~f) The design of the structure should be adequate to resist seismic forces assumed to act nonconcurrently in the direction of each of the main axes of the structure.~~

3.~~3~~4.4.~~2~~3 Locations Outside the United States. If peak rock accelerations determined by the more exact method discussed in paragraph 3.~~3~~4.4.1 and 3.4.4.2 are not available, bedrock accelerations, assigned on the basis of seismic risk zones, as specified in the AASHTO criteria, may be used. Seismic risk zones are related to maximum earthquake intensity, measured on the Modified Mercalli (MM) Intensity Scale (1931) as follows:

Zone 0 .... No damage

Zone 1 .... Minor damage, MM V and VI

Zone 2 .... Moderate damage, MM VII

Zone 3 .... Major damage, MM VIII and larger

Zone 4 .... Great damage, areas within Zone 3 close to a major fault system

Seismic zones for locations outside of the United States are listed below:

Location	Seismic Zone	
Caribbean Sea:	Bahama Islands	1
	Canal Zone	2
	Leeward Islands	3
	Puerto Rico	3
	Trinidad Island	2
Mediterranean Sea:	Turkey (Ankara)	2
	Turkey (Karamursel)	3
	Rota, Spain	1
Atlantic Ocean:	Azores	2
	Bermuda	1
	Greenland	1
	Iceland (Keflavik)	3
Indian Ocean:	Diego Garcia	2
Pacific Ocean:	Caroline Islands (Koror, Palau)	2
	Caroline Islands (Ponape)	0
	Johnston Island	1
	Mariana Islands (Guam	3
	Mariana Islands (Kwajalein)	1
	Mariana Islands (Saipan)	3
	Mariana Islands (Tinian)	1
	Marcus Island	1

Location	Seismic Zone	
	Okinawa	3
	Philippine Islands	3
	Samoa Islands	3
	Wake Island	0

3.~~3~~4.4.~~3~~4 Embankments and Fills. For determining the stability of embankments and fills at solid wharves, when subjected to earthquake forces, refer to Naval Facilities Engineering Command NAVFAC DM-7.02, Foundations and Earth Structures~~, and NAVFAC DM-25.04, Seawalls, Bulkheads and Quaywalls~~.

3.~~3~~4.4.~~4~~5 Floating Structures. Usually, floating structures are not directly affected by seismic events. However, waves created by offshore seismic activity such as a seiche and tsunami will affect floating structures. Also, the mooring system employed (spud piles and chain) will be subjected to the ground motions and should be investigated.

3.~~3~~4.5 Earth and Water Pressures.

3.~~3~~4.5.1 Static Case. Static earth pressures, acting on retaining structures, are determined in accordance with the criteria detailed in NAVFAC DM-7.02.

3.~~3~~4.5.2 Dynamic Case. Seismic forces may cause increased lateral earth pressures on earth-retaining wharf structures accompanied by lateral movements of the structure. The degree of ground shaking that retaining structures will be able to withstand will depend, to a considerable extent, on the margin of safety provided for static loading conditions. In general, wharf retaining structures, designed conservatively for static loading conditions, may have a greater ability to withstand seismic forces than those designed, more economically, by less conservative procedures. Methods for determining lateral earth pressures due to seismic forces are discussed in NAVFAC DM-7.02.

3.~~3~~4.5.3 Water Pressure. Pressures due to water level differentials, resulting from tidal fluctuations and/or groundwater accumulations, should be considered in the design of sheet pile bulkheads, cells, and curtain walls, and in stability investigations for embankments and fills. Additional loading due to hydrodynamic pressure for retaining structures as addressed in NAVFAC DM-7.02 should also be considered in seismic areas. ~~For an estimation of the amount of tidal lag, refer to NAVFAC DM-25.04.~~

3.~~3~~4.6 Thermal Loads.

3.~~3~~4.6.1 Temperature Differential. The effect of thermal forces that build up in the structure due to fluctuations in temperature from what was measured at the time of construction should be considered. For piers and wharves which, by definition, are constructed along waterfronts, the large body of water available has a substantial moderating effect on the structure. Consequently, the structure may not attain an overall temperature 10 deg. F to 20 deg. F higher or lower than the water temperature. The effect will be even less for ballasted deck construction. However, unballasted decks may see a large temperature differential through depth. Solid-type piers and wharves and floating structures are less likely to be affected by temperature variations.

3.~~3~~4.6.2 Pile-Supported Structures. Typically, decks of pile-supported structures will be subjected to temperature differential. However, since the axial stiffness of the deck elements will be much higher than the flexural stiffness of piles, the deck will expand or contract without any restraint from piles (for narrow marginal wharves, the short inboard piles may offer some restraint, and hence need to be analyzed) and will subject the piles to bending moments and shear forces. Batter piles should be located so as not to restrain thermal motion (usually in the middle portion of a long structure).

3.~~3~~4.7 Ice Forces. In addition to the weight of accumulated ice on the structure, consider the forces exerted by floating ice. The principal modes of action of floating ice are shown in Figure 24 and discussed below.

3.~~3~~4.7.1 Dynamic Impact. Follow the criteria in the AASHTO standard to the extent feasible. For lightly loaded structures and for open pile platforms, these criteria may result in structures of unreasonable proportions. In such cases, consider reducing the AASHTO criteria in accordance with the Canadian code. See Charles R. Neill, "Dynamic Ice Forces on Piers and Piles," Canadian Journal of Civil Engineering, Vol. 3, 1976. The values of effective pressure are

AASHTO .... 400 psi
Canadian Code .... 100 to 400 psi (highway bridges)
Canadian Code .... 200 to 250 psi (wharf piles)

3.~~3~~4.7.2 Static Pressure. Freshwater ice will exert less pressure on a structure than seawater ice of the same thickness. For freshwater ice, pressures of 15 to 30 psi may be assumed. For sea ice, pressures of 40 psi to as much as 150 psi may be assumed. These are maximum values and relate to crushing of the ice. If the ice sheet can ride up on the nearby shore, the pressure exerted will be less than if the ice sheet is confined within vertical boundaries.

3.~~3~~4.7.3 Slow Pressure. Broken ice floes will exert less pressure than a solid ice sheet. In general, the pressures developed in this mode of action will be less than those to be experienced under the static pressure mode of action. Reliable values of pressure are not presently available.

3.~~3~~4.7.4 Vertical Movement. Assume that the structure will lift or depress a circular sheet of ice. Calculate the radius of the affected ice sheet on the basis of the flexural strength of ice as 80 to 200 psi. Check the shear on the basis of the strength (and adhesion) as 80 to 150 psi. Consider the formation of bustle (added thickness) of ice around the structure. See Bernard Michel, Ice Pressure on Engineering Structures, Monogram III-B1B, U.S. Army Cold Regions Research Engineering Laboratory.

3.~~3~~4.8 Shrinkage. Open pier and wharf decks which are usually constructed from concrete components are subject to forces resulting from shrinkage of concrete from the curing process. Shrinkage loads are similar to temperature loads in the sense that both are internal loads. For long continuous open piers and wharves and their approaches, shrinkage load is significant and should be considered. However, for pile-supported pier and wharf structures, the effect is not as critical as it may seem at first because, over the long time period in which the shrinkage takes place, the soil surrounding the piles will slowly "give" and relieve the forces on the piles caused by the shrinking deck. The Prestressed Concrete Institute PCI Design Handbook is recommended for design.

3.~~3~~4.9 Creep. This is also a material-specific internal load similar to shrinkage and temperature and is critical only to prestressed concrete construction. The creep effect is also referred to as rib shortening and should be evaluated using the PCI Design Handbook.

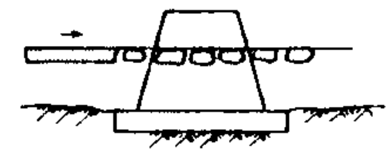
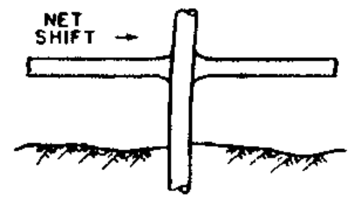
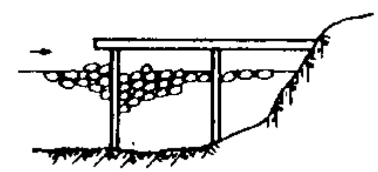
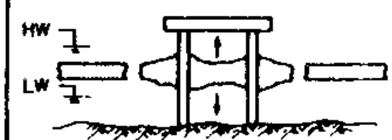
No.	DESCRIPTION	TYPICAL ENVIRONMENT	ILLUSTRATION
1	IMPACT OF MOVING SHEETS AND FLOES.	RIVERS AT BREAK-UP, COASTAL WATERS WITH APPRECIABLE CURRENTS.	
2	STATIC PRESSURE FROM EXPANDING OR CONTRACTING SHEETS.	LAKES, SHELTERED COASTAL WATERS. TEMPERATURE CHANGES AND JACKING BY REFREEZING OF CRACKS.	
3	SLOW PRESSURE FROM ICE PACK OR JAM.	EXPOSED COASTAL WATERS, RIVERS.	
4	VERTICAL MOVEMENT	TIDAL LOCATIONS WITH HEAVY ICE BUILD-UP.	

Figure 24
Principal Modes of Ice Action

3.~~4~~5 Load Combinations.

3.~~4~~5.1 General. Piers and wharves should be proportioned to safely resist the load combinations represented by Table 6. Each component of the structure and the foundation elements should be analyzed for all the applicable combinations. Table 6 lists load factors (f-) to be used for each combination and the percentage of unit stress applicable for service load combinations. The algebraic signs (+ or -) should be those that produce the most unfavorable (yet realistic) loading.
EQUATION:

$$S_i \text{ or } U_i = f_D\,(D) + f_L\,(L_c{+}I \text{ or } L_u) + f_{Be}\,(Be) + f_B\,(B) + f_C\,(C) + f_E\,(E) + f_{Eq}\,(Eq) + f_W\,(W) + f_{Ws}\,(Ws) + f{+}_{RST}\,(R + S + T) + f{+}_{Ice}{+}\,(Ice) \qquad (1)$$

where

- S_I = Service load combination
- U_I = Ultimate load combination
- f_x = Load factor listed in Table 6

3.~~4~~5.2 Load Symbols. The following load symbols are applicable for Equation (1):

- D = Dead load
- L_u = Live load (uniform)
- L_c = Live load (concentrated)
- I = Impact load(for L_c only)
- B = Buoyancy load
- Be = Berthingload
- C = Current load
- E = Earth pressure load
- Eq = Earthquake load
- W = Wind load on structure
- Ws = Wind load on ship
- R = Creep/rib shortening
- S = Shrinkage
- T = Temperature load
- Ice = Ice pressure

3.~~4~~5.3 Service Load Design. Timber structures for piers and wharves should be proportioned using the service load combinations and allowable stresses. Concrete and steel structures may also be designed using the above approach. The service load approach should also be used for designing all foundations and for checking foundation stability.

3.~~4~~5.4 Load Factor Design. Concrete structures for piers and wharves maybe proportioned using the load factor (ultimate strength) method; however, they should be checked for serviceability and construction loads.

Table ~~6~~5

Load Combinations, Load Factors (f_x), and Allowable Stresses

Service Load Design									
	S1	S2	S3	S4	S5	S6	S7	S8	S9
D[a]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
L_c+I or L_u	1.0	0.1	1.0	1.0		1.0	b	1.0	
B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
B_e		1.0							
C			1.0	1.0	1.0	1.0			1.0
E	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Eq							1.0		
W			0.3		1.0	0.3			1.0
W_s			0.3		1.0	0.3			
R+S+T				1.0	1.0	1.0			
Ice								1.0	1.0
% Allowable Stress	100	100	125	125	140	140	133	140	150

Load Factor Design									
	U1	U2	U3	U4	U5	U6	U7	U8	U9
D[a]	1.3	1.3	1.3	1.3	1.25	1.25	1.3	1.3	1.2
L_c+I or L_u	1.7[c]	0.17	1.3	1.3		1.25	b	1.3	
B	1.3	1.3	1.3	1.3	1.25	1.25	1.3	1.3	1.2
B_e		1.7							
C			1.3	1.3	1.25	1.25			1.2
E	1.3	1.3	1.3	1.3	1.25	1.25	1.3	1.3	1.2
Eq							1.3		
W			0.3		1.25	0.3			1.2
W_s			0.3		1.25	0.3			
R+S+T				1.3	1.25	1.25			
Ice								1.3	1.2

(a) 0.90 for checking members for minimum axial load and maximum moment.

(b) 0.0, 0.10, or 0.20, depending on the live load assumed to be action on pier for earthquake load calculations. See Earthquake Loads, paragraph 3.~~3~~4.4

(c) 1.3 for maximum outrigger float load from a truck crane.

Section 4. STRUCTURAL DESIGN

4.1 Types of Construction

4.1.1 Open Piers and Wharves. ~~Depending on the materials and concepts used, the facility can be constructed by any of the following methods:4.1.1.1 Conventional.~~ Typically, an open pier or wharf consists of a system of plumb or batter piles on which a deck is constructed. The piles may be made of steel, precast concrete, precast prestressed concrete, timber, and steel/ concrete composite. ~~In a marginal wharf, this system may be supplemented by a line of bulkhead (steel or concrete sheet pile, cast-inplace concrete wall) on the shoreside.~~ The deck is usually made of concrete although, for light-duty facilities, a timber deck may be used. The more popular concrete decks may be all cast in place, all precast, or a composite of the two.

~~4.1.1.2 Jack-up Barge. See Figure 25. This type consists of a structural steel seaworthy barge provided with openings for steel caissons which are lowered to the harbor bottom when the barge has been floated into final position. The barge may be completely outfitted during construction with ship fenders, deck fittings, and utilities including power, lighting, communications, water supply, sanitary facilities, etc., so that once it is jacked into position and utility tie-ins are made, it is ready to receive ships. Circular pneumatic gripping jacks, mounted on the deck above the caisson openings, permit the barge to be elevated in steps. The barge is loaded with steel caissons, a crane for pile erection, and other tools and materials required for the field work, and is towed to the site.~~

~~At the site, the barge is moved into approximate position and the caissons are dropped through the jacks and hull by the crane. The caissons, suspended above the harbor bottom and supported by engaging the jacks, are seated into the harbor bottom by dead weight. The barge-like deck is jacked to the required elevation and locked. Each caisson is then released from its jack and driven to refusal or required penetration. Each caisson is then released from its jack and driven to refusal or required penetration. When all caissons are driven, the hull of the barge is welded to the caisson, the jacks are removed, and the caissons are cut off flush with the deck and capped with steel plates. In some situations, the caissons are filled with sand to avoid buoyancy problems. Jack-up barge type structures are also constructed using hydraulic jacks and open-trussed towers instead of pneumatic jacks and circular caissons.~~

~~4.1.1.3 Template. See Figure 26. This type involves the fabrication of the various structural components of the pier, transportation of the pre-fabricated units to the construction site by barge, and erection of the prefabricated units to form the completed facility. As noted under jack-up barge, the template type pier may be outfitted, beforehand, with the utilities, deck fittings, and services that are needed to produce a fully~~

~~working berthing facility.~~

~~retrieve Figure 25. Open Pier, Jack-up Barge Type~~
~~retrieve Figure 26. Open Pier, Template Type~~

~~The prefabricated structural steel units consist of templates, deck assemblies made up of cap beams or trusses and stringers, tubular piles, fender units, decking (timber or concrete), fittings, and miscellaneous hardware. The template is an assembly consisting of four or more tubular columns connected with tubular bracing and welded together to form a structure of height approximately equal to the depth of water in which it is to be installed. A floating crane is used to transfer the template from the transporting barge and position it on the harbor bottom. Steel piles are placed through the template tubular columns and driven to refusal or the required penetration. If the harbor bottom is very soft, the template is held in a suspended condition while the steel tubular piles are placed and driven through the template columns. After pile driving, the space between the piles and the template columns is filled with grout. As succeeding templates are erected, deck units, decking, fender units, and fittings are placed to form the completed marine facility.~~

4.1.2 Solid Piers and Wharves. Typically solid piers and wharves consist of an earth retaining structure which provides a vertical face for mooring vessels. The earth retaining structure may be a sheet pile bulkhead with a deadman or pile anchor system, a sheet pile bulkhead with a relieving platform, closed sheet pile cells, reinforced concrete caisson, or precast concrete blocks. See Section 2, paragraph 2.5, for ~~different methods~~additional discussion of solid-type construction.

4.1.3 Floating Piers and Wharves. Floating piers and wharves consist of prefabricated barges, or closed cell units of steel or concrete that are floated into position and anchored in place. See Section 2, paragraph 2.5, for ~~different methods~~additional discussion of floating-type construction.

4.1.4 **Non-Conventional Site Specific Structures.** At remote and forward deployments sites, or where specific site conditions warrant, piers and wharves may be constructed using one of the following methods:

4.1.4.1 Jack-up Barge. See Figure 25. This type consists of a structural steel seaworthy barge provided with openings for steel caissons which are lowered to the harbor bottom when the barge has been floated into final position. The barge may be completely outfitted during construction with ship fenders, deck fittings, and utilities including power, lighting, communications, water supply, sanitary facilities, etc., so that once it is jacked into position and utility tie-ins are made, it is ready to receive ships. Circular pneumatic gripping jacks, mounted on the deck above the caisson openings, permit the barge to be elevated in steps. The barge is loaded with steel caissons, a crane for pile erection, and other tools and materials required for the field work, and is towed to the site.

At the site, the barge is moved into approximate position and the caissons are dropped through the jacks and hull by the crane. The caissons, suspended above the harbor bottom and supported by engaging the jacks, are seated into the harbor bottom by dead weight. The barge-like deck is jacked to the required elevation and locked. Each caisson is then released from its jack and driven to refusal or required penetration. Each caisson is then released from its jack and driven to refusal or required penetration. When all caissons are driven, the hull of the barge is welded to the caisson, the jacks are removed, and the caissons are cut off flush with the deck and capped with steel plates. In some situations, the caissons are filled with sand to avoid buoyancy problems. Jack-up barge type structures are also constructed using hydraulic jacks and open-trussed towers instead of pneumatic jacks and circular caissons.

4.1.4.2 Template. See Figure 26. This type involves the fabrication of the various structural components of the pier, transportation of the pre-fabricated units to the construction site by barge, and erection of the prefabricated units to form the completed facility. As noted under jack-up barge, the template type pier may be outfitted, beforehand, with the utilities, deck fittings, and services that are needed to produce a fully working berthing facility.

The prefabricated structural steel units consist of templates, deck assemblies made up of cap beams or trusses and stringers, tubular piles, fender units, decking (timber or concrete), fittings, and miscellaneous hardware. The template is an assembly consisting of four or more tubular columns connected with tubular bracing and welded together to form a structure of height approximately equal to the depth of water in which it is to be installed. A floating crane is used to transfer the template from the transporting barge and position it on the harbor bottom. Steel piles are placed through the template tubular columns and driven to refusal or the required penetration. If the harbor bottom is very soft, the template is held in a suspended condition while the steel tubular piles are placed and driven through the template columns. After pile driving, the space between the piles and the template columns is filled with grout. As succeeding templates are erected, deck units, decking, fender units, and fittings are placed to form the completed marine facility.

4.2 Construction Materials.

4.2.1 Timber. For the major functional types such as ammunition, berthing, repair, fitting-out/refit, and supply piers and wharves subject to high concentrated wheel loads, timber construction should not be considered. For light-duty piers and wharves, such as fueling, temporary, and degaussing/ deperming facilities, timber framing for deck and piling may be considered. However, timber may be more effective and optimal for fender systems, dolphins, walkways, utility trays, and deck-supported small buildings. Further consideration should be given to the use of treated timber piling in the marine environment in that some jurisdictions do not permit the use of treated timber. Consult with the local activity and field division for local requirements.

4.2.1.1 Preservative Treatment. All timber members exposed to the marine environment and immersed in salt water or fresh water should be pressure treated with oilborne (creosote, pentachlorophenol) or waterborne (salts) chemical preservative to protect against deleterious effects of decay, insects, and marine borers. Fender piling in less severe environments may be untreated. In warmer waters where severe

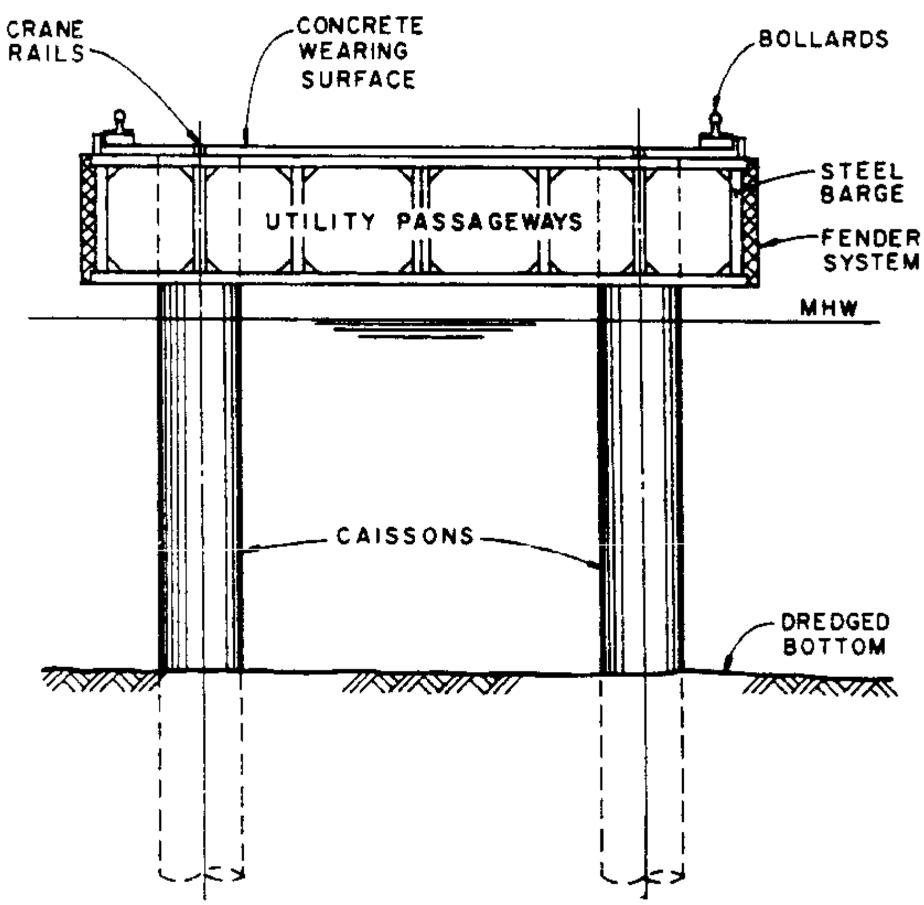


Figure 25
Open Pier, Jack-up Barge Type

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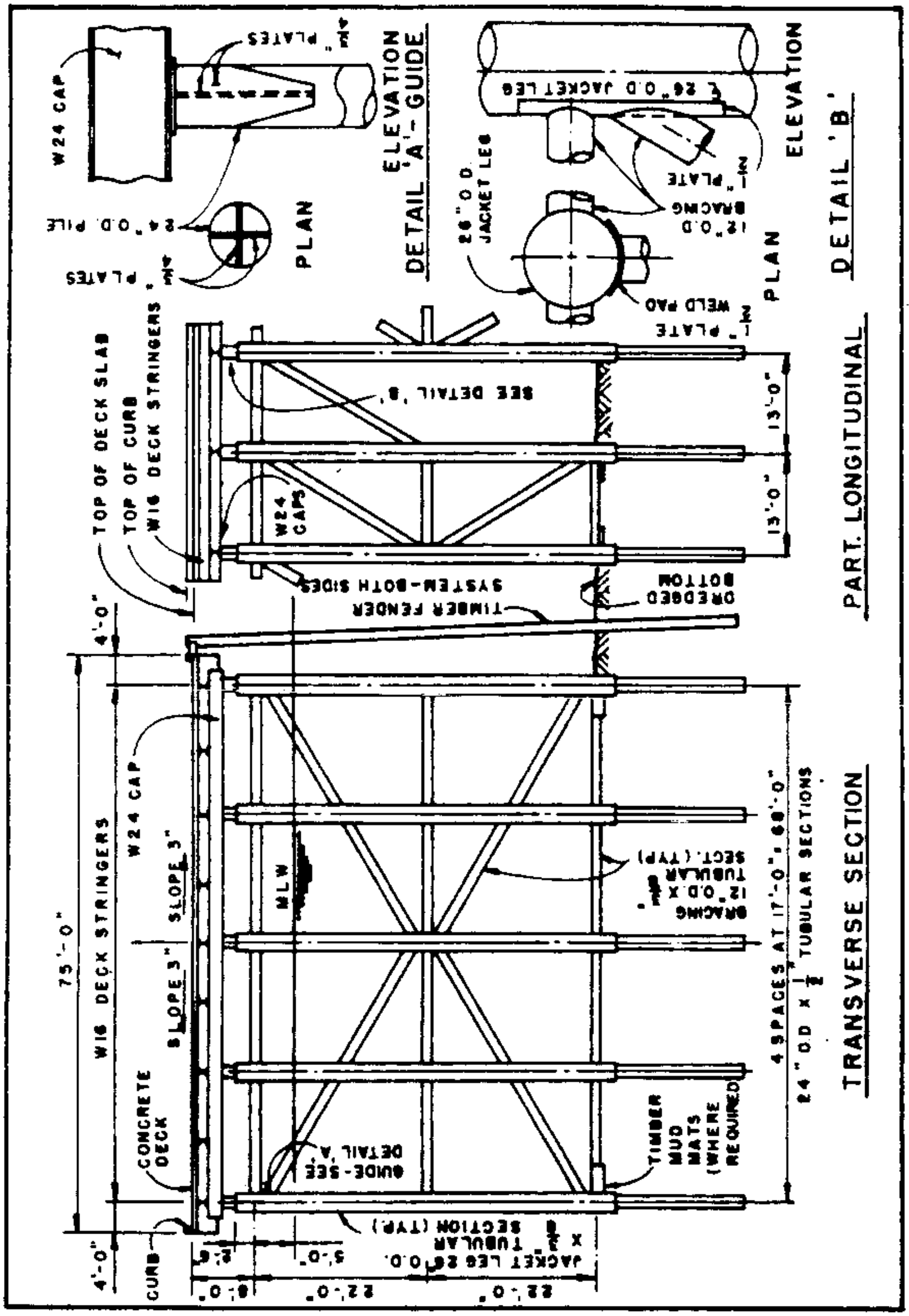

Figure 26
Open Pier, Template Type

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marine borer activity can be anticipated, dual treatment using both creosote and salt should be employed. The staff entomologist at the cognizant field division should be consulted for specific information on marine organisms present in the waters and the treatment required.

Preferably, treatment should be made after all holes and cuts are made. When holes and cuts are made in the field, timber members should be treated with preservative to prevent borer activity from starting in the holes. This is difficult to do properly in the tidal zone, and especially so below mean low water. Design and detailing should be such as to avoid the necessity for making cuts or holes on piles underwater where treatment is difficult. Where possible, avoid bracing or connections below mean low water. All connection hardware should be suitable for the saltwater immersion and exposure. For above-water construction, waterborne salt treatment is preferable as creosote treatment stains clothing and smears on equipment.

4.2.1.2 Timber Species. Douglas fir and southern pine are the more popular species for waterfront construction. Southern pine piles are limited to 65 ft in length, whereas Douglas fir piles and poles can be used up to 100-ft lengths. Large beams and timber sizes needed for chocks and walers are generally available only in Douglas fir and southern pine. Chocks and walers should be treated with waterborne salts and not oilborne preservatives such as creosote. The cost and availability of timber piles and other members should be evaluated for the project site under consideration.

4.2.2 Steel. When protected against corrosion by the use of coal tar epoxy or other marine coatings and cathodic protection systems, steel construction may be considered for all types of marine structures. However, active cathodic systems are difficult to design, construct, and maintain properly. Passive systems are preferred. Additional steel thickness may be provided as a sacrificial corrosion allowance. Steel is particularly adaptable for use in template and jack-up barge construction at advance base facilities, as piles for structures located in deep water where high lateral forces must be resisted, as fender piles and fender panels, as piles for structures located in areas of high seismic activity, and where difficult driving is anticipated. When the utilization of other construction materials is considered feasible, the use of steel construction may be restricted by cost and maintenance requirements.

4.2.3 Concrete. For piers and wharves, concrete is generally the best material for construction. Properly designed and constructed facilities are highly durable in the marine environment. New advances in concrete technology have improved concrete durability. Concrete enhanced with flyash, silica fume and corrosion inhibitors have demonstrated superior performance and should be used whenever possible. In addition, the use epoxy coated reinforcement is recommended. Concrete is immune to marine borer and insect attack and is incombustible. ~~Precast concrete piles should preferably be prestressed to resist the tensile forces frequently~~

~~encountered during driving. Corrosion of reinforcement in prestressed concrete piles even after cracking can be controlled by proper mix design and, in extreme cases, by epoxy coating the reinforcement. However, sufficient control must be exercised during driving of concrete piles to reduce cracking to a minimum. Where difficult driving into very compact sands, gravels, or rock is anticipated, the tip of the piles may be equipped with a WF-shape or H-pile "stinger" to achieve needed penetration. Very large hollow cylindrical piles (48-in. diameter and more) have been successfully employed for waterfront construction.~~ Concrete is also ideal for deck construction in open-type piers and wharves and, when properly designed, is more economical for floating structures. Proprietary stainless steel reinforcement bars, wires, and strands have been developed for use in concrete construction where nonmagnetic properties are desired as in degaussing/deperming facilities.

4.2.3.1 **Precast Concrete Piles.** Precast concrete piles should preferably be prestressed to resist the tensile forces frequently encountered during driving. Corrosion of reinforcement in prestressed concrete piles even after cracking can be controlled by proper mix design and, in extreme cases, by epoxy coating the reinforcement. However, sufficient control must be exercised during driving of concrete piles to reduce cracking to a minimum. Where difficult driving into very compact sands, gravels, or rock is anticipated, the tip of the piles may be equipped with a WF-shape or H-pile "stinger" to achieve needed penetration. Very large hollow cylindrical piles (48-in. diameter and more) have been successfully employed for waterfront construction.

4.2.4 Composite. ~~Although not very popular,~~ ~~composite~~ Composites ~~piles~~ made of concrete and steel, concrete and fiberglass, and plastic and fiberglass have been successfully employed in piers and wharves. Composites offer many advantages over conventional materials but often have limitations that need to be considered. Some advantages may include improved corrosion resistance, lightweight, and ease of construction. Some of the disadvantages may include low strength, UV light deterioration, long term durability and high cost. These issues should be investigated in depth.

4.2.4.1 **Concrete and Steel.** Concrete-filled pipe piles, ~~and~~ steel H-piles with a concrete casing, and steel beams with concrete decks are the more common types. The concrete casing or jacket for the ~~latter type~~ steel H-piles may be required only in the splash or tidal zone. Concrete is sometimes added to steel pipe piles for deadweight purposes to resist uplift forces but reinforced concrete can be used to increase the stiffness of the pile.

4.2.4.2 **Concrete and Fiberglass.** Concrete filled fiberglass piles have been used in facilities where high axial capacities are not required. The lightweight fiberglass piles are easily installed and do not require high capacity handling equipment.

4.2.4.3 **Plastic and Fiberglass.** Fiberglass reinforced plastic piles and beams have been successfully used in pier and wharf construction primarily as fender piles, wales and chocks. Design guidance for use in fender systems is provided in SP-draft2-SHR, **Proposed Design Criteria for Chocks and Wales.**

4.2.5 Aluminum. For deck-supported structures and supporting of piping and conduits, aluminum members are useful. However, unprotected aluminum should not be used under water or in the splash zone. Also, to prevent corrosion, aluminum should be electrically isolated from adjacent materials by nonconductive gaskets, washers, or bolt sleeves. Aluminum construction is used in the superstructure of degaussing/deperming facilities, due to the nonmagnetic characteristics of the material.

4.2.6 Plastics. Fiberglass-reinforced plastics (FRP) and ultra high molecular weight (UHMW) plastics are being increasingly used in waterfront construction. FRP grating and shapes are highly durable in the marine environment when shielded from ultraviolet rays. UHMW plastics are useful in fender systems design as rubbing strips where a high abrasion resistance and low coefficient of friction are required. UHMW plastics are available in various grades.~~However, these are fairly new materials of construction for piers and wharves and due caution should be exercised in their selection and usage.~~ The use of corrosion-resistant fiber reinforced plastic (FRP) components including reinforcing bars, prestressing tendons, structural shapes, and unidirectional or woven fabrics, are being developed and have been successfully used in the repair of piers and wharves. The use of these type of materials may be considered when the situation warrants. Special attention to connections needs to be provided. The use of these materials for new construction should be carefully evaluated.

4.3 Allowable Stresses.

4.3.1 General. Allowable stresses for materials used in pier and wharf construction generally conform to industry standard codes for the type of material and the purposed application unless modified herein. ~~Naval Facilities Engineering Command NAVFAC DM-2.01, Structural Engineering - General Requirements. Applicable service classifications are described in NAVFAC DM-2.01 and are based on the type of loading. For example, elements designed for moving concentrated loads should be proportioned to criteria for Service Classification A. Elements designed for uniform loads or static (or fixed) concentrated loads should be proportioned to criteria for Service Classification B. Elements subject to both types of loading should be proportioned for the more critical of the two criteria.~~ Allowable stresses for fender system design are discussed in Section 5, paragraph 5.4.4.3.

4.3.2 Timber. ~~Refer to Naval Facilities Engineering Command NAVFAC DM-2.05, Structural Engineering - Timber Structures, for design standards.~~ Design timber structures in accordance with the National Forest Products

Association (NFPA), **National Design Specification for Wood Construction.** Allowable stresses are generally not affected by preservative treatment. However, modulus of rupture and modulus of elasticity are considerably reduced by preservative treatment. See Table 4 of MIL-HDBK 1025/6,~~Naval Facilities Engineering Command NAVFAC DM-25.06,~~ General Criteria for Waterfront Construction. When preservative treatment for fire retardation is used, the allowable stresses should be reduced by 10 percent. {Some additional guidance is needed in regard to the use of fire retardation!}

4.3.3 Steel. ~~Refer to Naval Facilities Engineering Command NAVFAC DM-2.03, Structural Engineering - Steel Structures, for design standards.~~Refer to the American Institute of Steel Construction (AISC), **Manual of Steel Construction**, Allowable Stress Design, Ninth Edition, for design standards. For pier and wharf structures subject to moving wheel loads and supported by structural steel members, refer to AASHTO for appropriate design standards.

4.3.4 Concrete. Refer to ~~Naval Facilities Engineering Command NAVFAC DM-2.04, Structural Engineering - Concrete Structures~~ AASHTO, PCI and ACI, for design standards. ~~Furthermore, for~~ For prestressed concrete ~~deck~~ members, “zero” tension design is preferred.~~ tensile stresses should be limited to 6 'fc' for Service Load Combination S1.~~ All reinforced concrete deck members should meet the crack control requirements for severe exposure.~~ Where members are continually and intermittently submerged, and where there is uncertainty as to whether an impermeable concrete will be obtained, epoxy-coated reinforcement and other corrosion protection methods should be considered.~~

4.3.5 Other Materials. ~~All other structural materials should be governed by requirements of MIL-HDBK-1002/6, Structural Engineering - Aluminum Structures, Masonry Structures, Composite Structures and Other Structural Materials.~~ Fiberglass-reinforced plastics (FRP), ultra-high molecular weight (UHMW) plastics, and other new materials should be governed by the accepted industry standards for structural design and detailing.

4.4 Deck Structure Design.

4.4.1 Deck Framing. Concrete is generally considered the best material for deck framing and should be used for most pier and wharf decks. Although timber, steel, steel/concrete composite, and timber/concrete composite decks have been used in the past, they are neither cost-effective nor suitable for the high concentrated load capacities currently demanded of decks. From durability, maintenance, and life-cycle cost viewpoints, a concrete deck is superior and is highly recommended. The deck framing should be slabs supported on pile caps, utilizing an all cast-in-place, all precast, or composite construction, as shown in Figure 27. For the concentrated loads which typically control the deck design, a solid slab with its high punching shear resistance is recommended. Framing systems using thin slabs, as in cast-in-place slab/beam/girder systems, should not be used because of their tendency to spall along beam/girder corners and edges. Occasionally, where high concentrated loads are not specified, voided slabs may be used. Map cracking in the cast-in-place topping at the precast panel joints is sometimes seen. To control the cracking, transverse post-tensioning is sometime utilized. For distribution of horizontal loads, pier and wharf decks should be continuous, with as few expansion joints as possible. Where expansion joints are needed, the deck on each side of the joint should be supported on a separate pile cap or girder.

4.4.2 Placement of Concentrated Loads. Vertical concentrated wheel loads from mobile cranes, trucks, and other vehicles and outrigger float loads from mobile cranes may be placed anywhere on the deck, ~~since~~because operational control is not feasible. Trench covers, ~~utilidor~~ utility trench covers, and access hatch covers should be designed to handle the concentrated loads, where they are accessible to mobile equipment. However, designated areas on the pier deck may be exempted from wheel loads or outrigger float loads, or designed for lesser loads, when curbs, railings, and other physical barriers are provided to isolate those areas from vehicle access.

4.4.3 Distribution of Concentrated Loads.

4.4.3.1 Truck, Forklift, Straddle Carriers. Concentrated wheel loads from these vehicles are applied through small "footprints" to the deck structure. The distribution of these loads and computation of maximum moments and shears may be in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Standard Specification for Highway Bridges. However, this method is ~~very~~ conservative and more reasonable results may be obtained using NCEL R-935, **Lateral load Distribution in One-way Flat Slabs**, ~~. Using~~ Adolf Pucher, Influence Surfaces for Elastic Plates, for different edge conditions. ~~yields more reasonable results.~~ or finite element analysis.

4.4.3.2 Mobile Crane Float Loading. Typically, truck-mounted mobile cranes make the lifts while supported by outriggers. To reduce the concentration of loads, manufacturers provide large pads or floats through which all the loads are applied to the deck. Operators can be expected not to locate the outrigger on small manhole covers and narrow light-duty trench covers which look obviously weak. However, they will locate the outrigger on all other areas. The float loading may be distributed and deck moments and shears computed using any of the methods for wheel loads. However, the influence surface approach is more appropriate and is recommended.

4.4.3.3 Railroad Loading. Wheel loads should be distributed to the deck members in accordance with the American Railway Engineering Association (AREA) Manual for Railway Engineering.

4.4.3.4 Rail-Mounted Crane Loading. Typically, rails for portal and container cranes are supported on separate crane girders or beams or pile caps. ~~Since~~ Because the wheel spacing of most cranes is no more than 4 ft, where crane support beams are at least 2 ft deep, the wheel loads may be converted to an equivalent line load.

4.4.3.5 Ballasted Deck. Where ballasted deck construction is used, the footprint of concentrated loads can be increased by assuming a 45 deg. distribution through the ballast and paving.

4.4.4 Distribution of Horizontal Loads. Piers and wharves are subjected to concentrated lateral loads from berthing and mooring of ships. The deck structure is expected to behave as a "shear diaphragm" and distribute the lateral loads to pile bents or to the bulkhead. The actual load received by any pile bent will depend on the relative stiffnesses of the pile bents and rigidity of the diaphragm. The behavior is analogous to a "beam on elastic foundation" and is best handled by a stiffness analysis using computers. For relatively simple and uniform bent spacing, hand calculations may be sufficient.

4.4.4.1 Berthing Forces. Berthing forces are considered to be transmitted by a berthing ship along an assumed contact length of fender system and then further distributed by the diaphragm action of the deck to the individual bents. See Figure 23. At marginal wharves, the retained upland fill absorbs the berthing force transmitted by the deck. At bulkheads where sheet piles are employed to retain upland fill, berthing forces are transmitted directly to the fill. At piers and wharves, horizontal berthing forces are resisted by batter piles, by adequately sized vertical piles, or a combination of both. Where the fender piles are used in conjunction with separators, only that part of the load transmitted at the deck level need be considered.

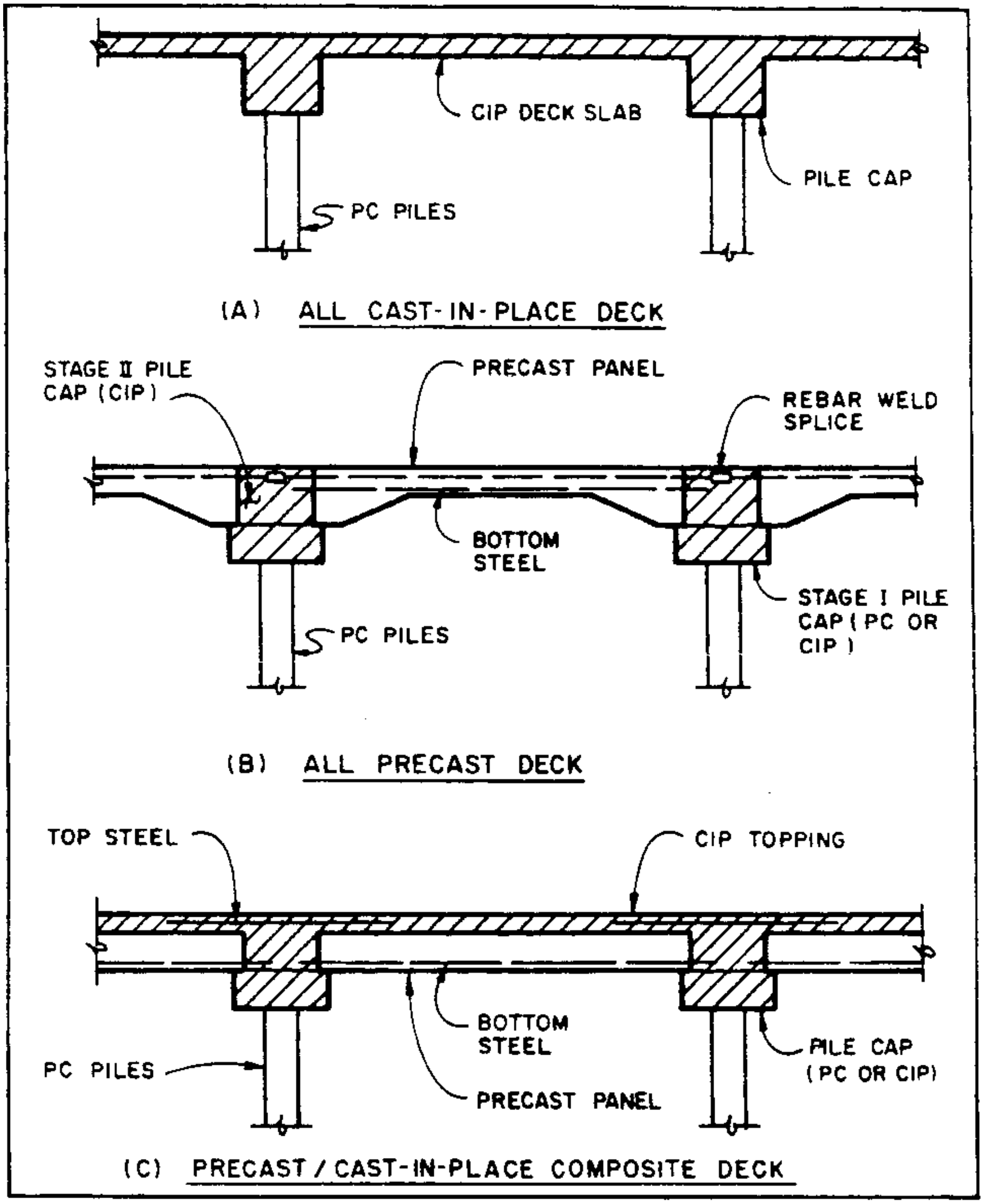

Figure 27
Concrete Deck Construction

4.4.4.2 Mooring Forces. Mooring forces are typically transmitted to piers and wharves by fenders, separators, camels and mooring lines. Determine mooring forces using methods defined in MIL-HDBK 1026/4, **Mooring Design**. When a continuous fender system is used, ~~The~~ the ship contact length, ~~, when separators are not used,~~ may be taken as 25 percent of ship's length for cruisers, destroyers, and frigates, and as 50 percent of ship's length for auxiliary and amphibious warfare ships. When separators or camels are used, the contact length is equal to the length of the separator or camel. Mooring forces acting away from piers or wharves are transmitted to the deck as point loads through deck fittings where mooring lines are attached. It should be remembered that mooring lines are often used at an upward angle for surface ships and at a downward angle for submarines.

4.4.5 Pile Caps. ~~For construction sequence reasons, in piers and wharves it~~ It is often cost-effective to orient pile caps (and hence pile bents) transverse to the length of the structure. This orientation provides improved lateral stiffness for berthing and mooring forces When this orientation is used, longitudinal pile caps are not needed unless crane trackage support or longitudinal seismic resistance is to be provided. For marginal wharves where lateral loads from mooring and berthing loads are transferred to the land, a longitudinal orientation of the pile cap may be considered if feasible for construction. Moments and shears on pile caps from live loads should take into account the elastic shortening of the piles and the effect of soil deformation at and near pile tips. For computation of forces from high concentrated loads, the cap behaves as a beam on elastic foundation, and distributes the concentrated load to a number of piles adjacent to the load. Again, while hand calculations are acceptable, a stiffness analysis using computers is recommended.

4.5 Substructure Design.

4.5.1 Pile Bent Framing. A pile-supported framing system is the most popular form for substructure design for open piers and wharves. Several framing concepts for open piers and wharves and marginal wharves are illustrated in Figure 28. Many variations and combinations of the illustrated concepts are possible.

4.5.1.1 All Plumb Pile System. The lateral loads are resisted by "frame action," whereby the piles and the cap form a moment frame and resist the lateral load primarily by the flexural stiffness of the piles. However, for narrow structures lateral deflection ~~will~~ may be ~~very~~ high for even small lateral loads. Also, sidesway is not prevented, which increases the effective length of pile as a column. Further, if piles vary in unsupported ~~height~~ length, the shorter piles will attract ~~most~~ a large portion of the lateral load. ~~Since~~ Because the piles are more efficient for axial loads and less so for bending moments, this framing usually is restricted to shallow waters and light lateral loads. However, for wide structures with a large number of piles, the total stiffness of the system may justify a reduced effective length. A more in depth stability analysis would need to be performed to validate a reduced effective length. In addition, large diameter steel pipe and precast/prestressed concrete cylinder piles can provide improved lateral stiffness and are attractive for use in areas of high seismic activity.

4.5.1.2 Plumb/Batter Pile Systems. In this type of framing, all the vertical loads are primarily handled by the plumb piles and lateral loads are resisted primarily by the batter piles. The behavior of the system is one of "truss action." This system is more cost-effective as the lateral loads are resisted primarily by the axial stiffness of the batter piles. However, very high forces are transmitted to the caps, which will have to be designed and detailed to resist these forces. In areas of high seismic activity, the increased stiffness of the system reduces the period and leads to higher earthquake loads.

4.5.1.3 All Batter Pile System. This system is a compromise between the two above, and is cost-effective in some circumstances. With this system, the batter slope may be near vertical. Natural periods can be as high as several seconds, making the approach attractive for seismic areas.

4.5.1.4 **Batter Pile System with Seismic Isolation.** This system incorporates calibrated isolators or seismic fuses between the wharf deck and batter piles. The system allows for high displacements of the wharf deck once a threshold lateral load causes the isolator slip. The designer needs to consider the magnitude of lateral berthing and mooring forces such that they do not exceed the threshold lateral force of the isolator. In this case a separate fendering structure may be required.

4.5.2 Lateral Loads on Piles. In addition to the axial loads, bending moments, and shears caused by lateral loads at deck level due to berthing, mooring and seismic forces, piles are also subjected to lateral loads acting along the length of the pile.

4.5.2.1 Current and Waves. These loads are applied at and near the water level and may be significant where large size piles are used in high-current waters. An estimate of current and wave forces can be made using the methods described in the Army Corp of Engineers, **Shore Protection Manual.**

4.5.2.2 Sloping Fill Loads. These loads are transmitted along the shaft of the piles by the lateral movement of the soil surrounding the piles beneath the structure, such as may occur along a sloping shoreline at marginal wharves, as shown in Figure 11. The maximum moments in the piles for this category of loadings are determined by structural analysis and the methods outlined in Naval Facilities Engineering Command NAVFAC DM-7.02, **Foundations and Earth Structures**, after the conditions of pile support in the pile cap and the soil have been established and the effective length of pile has been determined.

a) Piles of relieving platform types of solid wharves, shown on Figure 12, may be subjected to lateral earth loads if the stability of the slope beneath the platform is ~~marginal~~ minimal and soil creep occurs. In such cases, stabilizing measures should be introduced, prior to installation of piles, to prevent movement of the soil along the slope. Among the stabilizing measures that may be used are surcharging (preloading), installation of sand drains or soil compaction piles, or replacement of unstable materials. If the piles

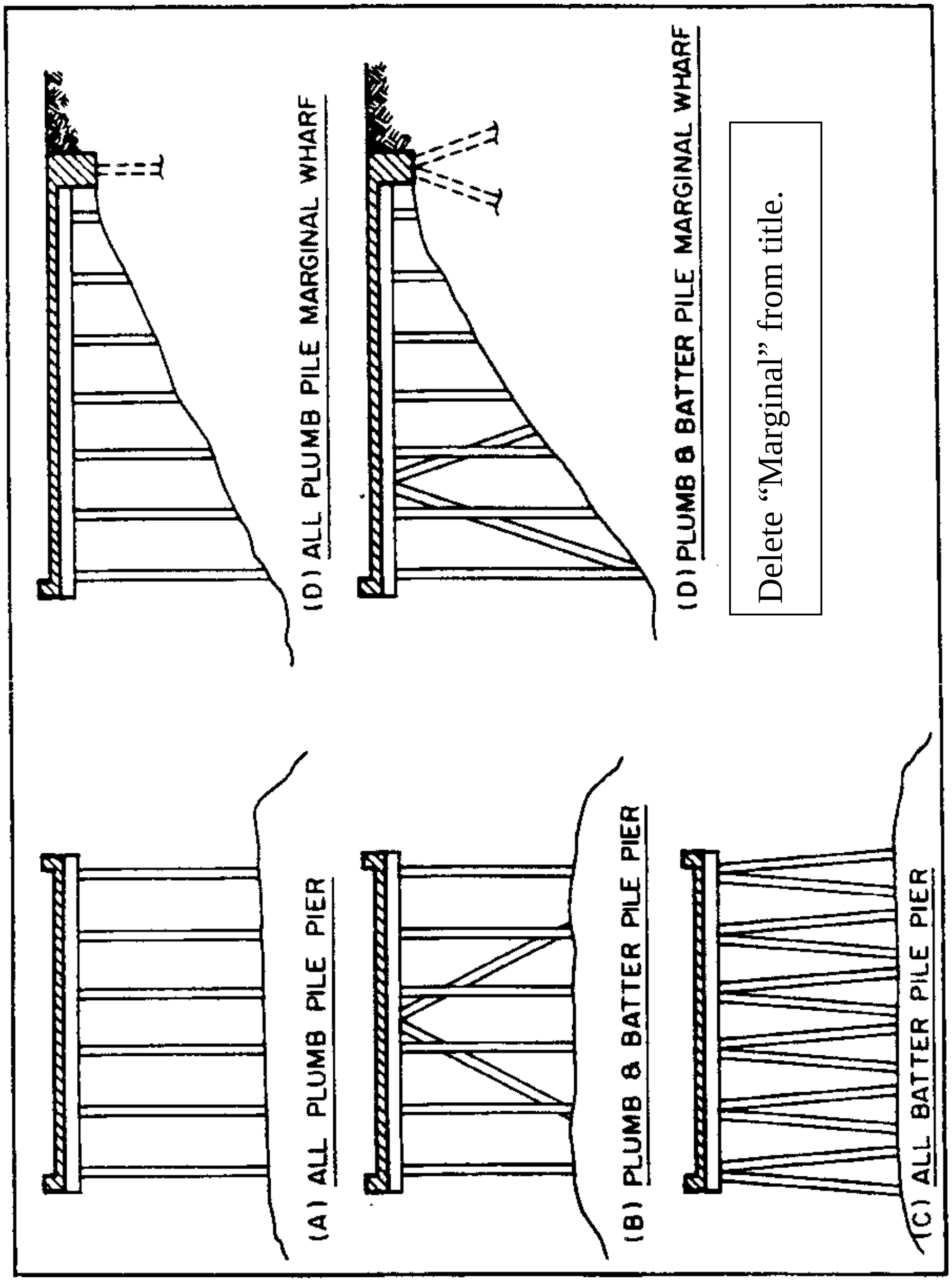

Figure 28
Substructure Framing Concepts

supporting the structure are used to increase slope stability, or if time-dependent stabilizing measures are introduced after the piles are in place, the resistance to soil movement provided by the piles should be calculated and the piles checked for the bending moments induced by the calculated lateral earth loads, in addition to the increased loading caused by the downdrag of the settling soil.

b) The pile resistance to soil movement may be obtained from a stability analysis by determining the additional resistance, provided by the piles, which will provide a factor of safety that corresponds to zero soil movement. The minimum factor of safety required for this tape of analysis varies and should be selected after evaluating the soil conditions which exist at the site. The embedment length of piles needed for developing the required lateral resistance may be determined in accordance with the criteria given in NAVFAC DM-7.02.

4.5.2.3 Dynamic Fill Loads. In general, piles subjected to seismic forces behave as flexible members and their behavior is controlled primarily by the surrounding soil. Both vertical and batter piles move together with the surrounding soil during an earthquake. Provided that shear failure or liquefaction of the surrounding soil does not occur during ground shaking, the pile-supported structure will move a limited amount and remain stable after an earthquake. The magnitude of the horizontal movement depends on the earthquake magnitude and duration, design details of the platform, flexibility of the piles, and the subgrade modulus of the foundation soil. If the soil surrounding the piles is susceptible to liquefaction or if slope failure occurs, the piles will move excessively, resulting in serious damage to the piles and the structure. For these conditions, unstable materials should be removed and replaced. When the piles penetrate a deep soft layer first and then a stiff layer of soil, the soils displace cyclically back and forth during an earthquake. During the cyclic ground shaking, the piles will move with the ground and return essentially to their original position if the soil does not fail during these cyclic displacements. Accordingly, if piles are to continue to safely support loads after an earthquake, it will be necessary for the piles to have the capability to withstand the induced curvature without failure. Practical design considerations for a semiempirical pile bending analysis are given in Edward Margason, Pile Bending During Earthquakes.

4.5.3 Pile Materials. Steel and concrete and composites of the two are the most common and viable pile materials for the substructure construction of piers and wharves. Wood piles may be used for lightly loaded structures and for fender systems. Load capacity geotechnical considerations and life-cycle costs should govern selection of the pile material. When steel piles are used, a suitable protective system (paints, cathodic protection, concrete or sand filling of pipe sections) should be specified for durability and reduced maintenance expenses. Prestressed concrete piles are preferred over reinforced concrete piles, because of the latter's susceptibility to cracking during driving and lack of watertightness.

Piles are subjected to high compressive and tensile stresses during driving and should be proportioned to resist these in addition to the service loads. Where prolonged driving in alternately soft and hard layers of soil or driving through stiff "quaky" clays is anticipated, very high tensile stresses are set up and will require a higher level of prestress (1000 psi or more) in prestressed concrete piles. Attention should be given to controlling driving stresses by specifying frequent cushion replacement, and by requiring use of hammers capable of adjusting driving energy.

In addition to steel, concrete and composite piles, materials such as plastic and fiberglass have been successfully used in pier and wharf construction. Plastic piles have primarily been used for fender piles and provide a durable alternative to timber piles. Concrete filled fiberglass pipe piles may provide suitable capacities for lightly loaded structures.

4.5.4 Solid Cellular Structures. For design procedures and selection of type, see NAVFAC DM-7.02,. Cellular structures are gravity retaining structures formed from the interconnection of straight steel sheet piles into cells. Strength of cellular structures derives from resistance to shear caused by friction of the tension in the sheet pile interlocks and also from the internal shearing resistance of the fill within the cells. Accordingly, clean granular fill materials such as sand and gravel are usually used to fill the cells. Extreme care must be exercised in the construction of cellular structures because excessive driving onto boulders or uneven bedrock may cause ruptured interlocks which can later unzip under hoop tension (from filling) and cause failures of the cell. Movement and expansion of cells must be compensated for during construction of the cells and fill placement carefully controlled if satisfactory alignment of the face of the wharf is to be maintained. Cellular structures are classified according to the configuration and arrangement of the cells. Three basic types are discussed below and are shown on Figure 13.

4.5.4.1 Circular. This type consists of individual large-diameter circles connected together by arcs of smaller diameter. Each cell may be completely filled before construction of the next cell is started. Construction of this type is easier than the diaphragm type because each cell is stable when filled and thus may be used as a platform for construction of adjacent cells.

Because the individual cells are self-supporting units, accidental loss of one cell will not necessarily endanger adjoining cells. Compared to a diaphragm type cellular structure of equal design, fewer piles per linear foot of structure are required. The diameter of circular cells is limited by the maximum allowable stresses in the sheet pile interlocks and, when stresses are exceeded, cloverleaf cells are used.

4.5.4.2 Diaphragm. This type consists of two series of circular arcs connected together by diaphragms perpendicular to the axis of the cellular structure. The width of cells may be widened by increasing the length of the diaphragms without raising interlock stress, which is a function of the radius of the arc portion of the cell. Cells must be filled in stages so that the heights of fill in adjoining cells are maintained at equal levels to avoid distortion of the diaphragm walls. Diaphragm type cells present a flatter faced wall than circular cells and are considered more desirable for marine structures.

4.5.4.3 Cloverleaf. This type is a modification of the circular cell type and is generally used in deep water where the diameter required for stability would result in excessively high interlock stress if diaphragms were not added.

4.5.5 Fill for Solid Structures. Granular free-draining material should be provided adjacent to sheet pile bulkheads, extending from dredged bottom to underside of pavement on grade. This material should be graded to act somewhat as a filter to limit subsequent loss of fines through the sheet pile interlocks. Placement of free-draining material should be in stages, commencing at the intersection of sheet piling and dredged bottom and progressing inshore. Mud and organic silt pockets should be eliminated. In general, hydraulic fill for backfill should not be considered unless provision is made for the effects of fill settlement, potential liquefaction of fill in seismic zones, and high pressure exerted on sheet piling. Vibro-compaction should be considered for consolidation of hydraulic fill. In areas with tidal ranges greater than 4 ft, 2 in. diameter weep holes should be provided for the sheet piles above the mean low water level. When weep holes are used, graded filters should be provided to prevent loss of finer backfill material. Openings in pavement or deck should be provided for replenishment of material in order to compensate for loss and settlement of fill. In general, flexible pavement using asphaltic concrete is preferred over rigid pavement with portland cement concrete, as it is more economical to maintain and better able to accommodate underlying settlement~~. For additional design criteria, refer to Naval Facilities Engineering Command NAVFAC DM-25.04, Seawalls, Bulkheads and Quaywalls.~~

4.5.6 Deterioration of Substructure. The following are the principal causes of deterioration:

4.5.6.1 Marine Borers. Wood piles are the only kind that will be affected by marine organisms. Preservative treatment used for wood piles and bracing under water should be selected for the particular organisms present in the water locally. While marine growth does occur on concrete and steel surfaces in the tidal zone, they have not proven to be damaging.

4.5.6.2 Corrosion. Steel and, to a lesser extent, concrete piles are subjected to corrosion from the alternative dry and wet conditions to which the substructure is subjected. However, corrosion in steel piles is significantly higher, especially in the splash zone. Hence, steel piles will require a good paint system or cathodic protection. Occasionally, a concrete jacket may be provided in the splash zone for steel piles. Prestressed concrete piles, when produced under quality control standards established by the Prestressed Concrete Institute (PCI) and employing a well-designed mix, have performed well over the years. However, in water containing high amounts of chlorides and sulphates, one or more of the following additional measures to increase durability may be required for proper performance. These measures include, but are not limited to, the following: High cement content (six sacks per cubic yard or more), low water/cement ratio (w/c 0.40 by weight), Type II or V cements (cements with tricalcium aluminate between 5 and 8 percent), high level of prestress (1000 to 1200 psi), use of a silica fume concrete with high range water reducer, and epoxy coating (for bar or strand reinforcement). In extreme cases, a protective paint system may be specified for the pile surfaces.

The use of concrete mix designs specifically formulated for use in the marine environment has become common. These concrete mix designs utilize high cement content, low water-cement ratios, high range water reducers, silica fume, pozzolan, fly ash, blast-furnace slag, and corrosion inhibiting admixtures.

For steel sheet pile bulkheads, a concrete fascia can be cast 2 to 3 feet below MLW to control corrosion in the slash zone and to protect critical tie-bolts and tie-rods. Epoxy coating should be used on the outer face of the steel sheet piles from 1 to 2 feet below MLW (1 foot above the bottom of the concrete fascia) to approximately 4 feet below the mud line. Critical tie-rods, tie-bolts, and channel walers for bulkheads should also have a high quality coating system. Where stray currents from shipyard activities, welding or impressed current protection systems on underground pipeline are a concern, impressed current cathodic protection systems may need to be considered. If the impressed current system system is proposed, consideration needs to be given to the activity’s ability to maintain the system (i.e., facility location, funding, qualified personnel, access, etc.).`

4.5.6.3 Abrasion. Floating debris and floating ice in open types of piers and wharves may cause serious abrasion to concrete piles. Timber jackets have been successfully used to protect the concrete piles, as illustrated in ~~NAVFAC DM-25.06~~ MIL-HDBK 1025/6.

4.6 Floating Structures.

4.6.1 Steel Pontoon Wharf.

4.6.1.1 General. Modular steel pontoon structures may be used for temporary facilities to berth ships up to loaded drafts of 30 ft. This structure type may be provided where it is not considered advisable to construct a fixed facility and at advanced bases where versatility and ease of deployment are required. The allowable uniform loading is limited, as is the capacity for mobile cranes. For additional information, see Naval Facilities Engineering Command NAVFAC P-401, Pontoon System Manual.

4.6.1.2 Navy Lightered (NL) P-Series Pontoon Wharves. NL pontoons are reinforced, welded steel cubes, 5 ft long, 7 ft wide, and 5 ft high, capable of accommodating HS-20 truck loading as specified by AASHTO. Pontoons are assembled into strings which are joined to form pontoon wharves and pontoon bridge units. Thus, a 6 x 18 pontoon wharf consists of 6 strings of 18 pontoons each. See Figure 29 for an example of a pontoon wharf located in water of sufficient depth to berth cargo ships with loaded drafts not exceeding 30 ft. The offshore wharf consists of four 6 by 18 pontoon wharf units and each access bridge is made up of two 4 x 18 pontoon bridge units. The number of pontoon bridge units required is a function of the water depth, tidal range, and degree of exposure. Many wharf configurations are possible. The pontoon bridges are connected to the wharf offshore and to a 2 x 6 sand-filled abutment onshore by heavy-duty hinges. Cable moorings are used to anchor both the wharf and the connecting bridges to shore. The location is maintained by pile dolphins placed along the perimeter of the facility. The wharf is also outfitted with bitts and fenders. A ship may be moored independently of the wharf by utilizing buoys, chain, and anchors.

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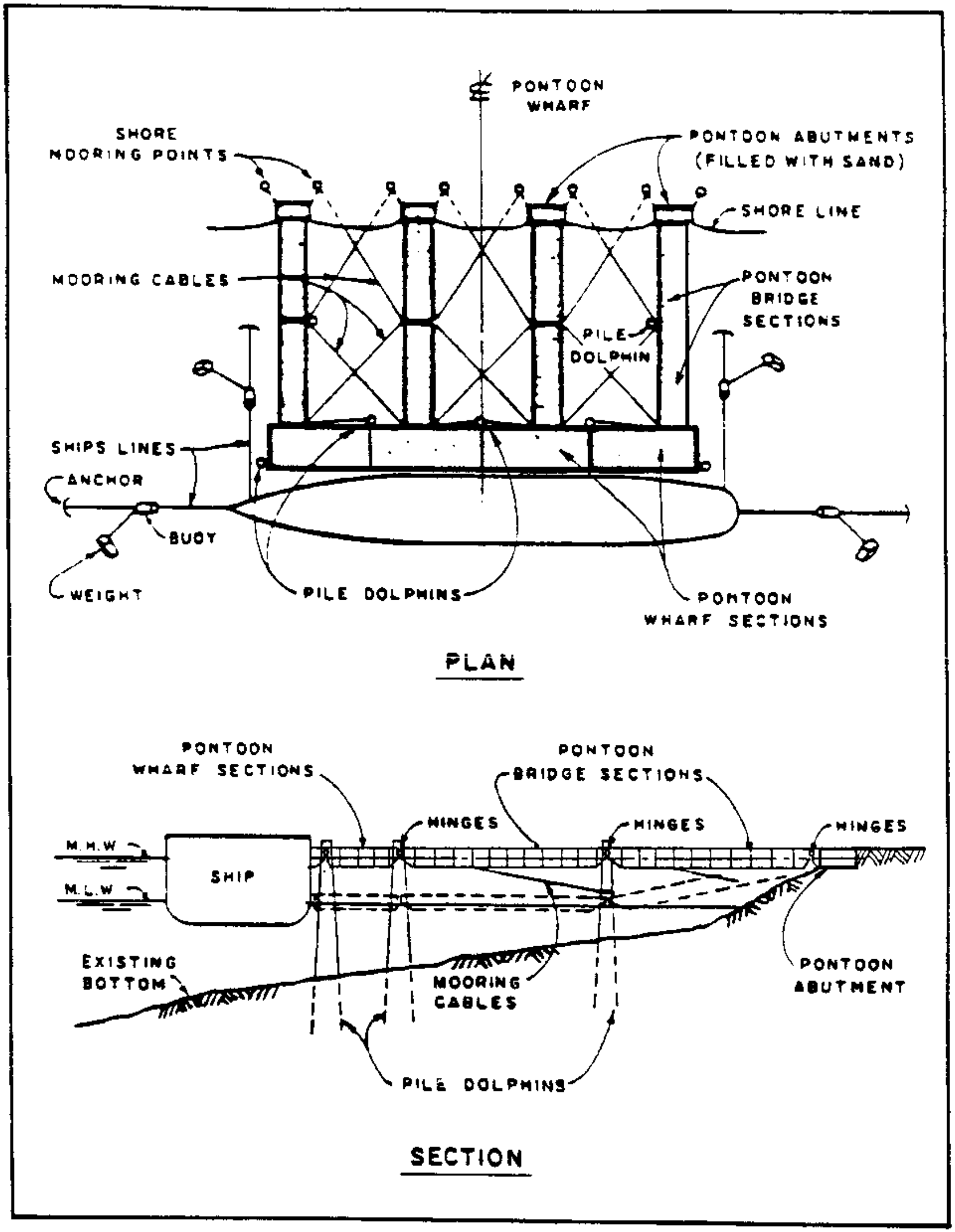

Figure 29
Pontoon Wharf

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4.6.1.3 Container-Sized Modular Pontoons. Commercially available modular causeway systems are becoming increasingly popular for naval operations. The pontoons are made from container-sized modules that can be stored and transported in commercial container ships. The modules are lifted out and assembled on calm water or launched from a ship's deck. (See Figure 30.) Cleats, bitts, and other hardware can be installed and removed as needed. With minor modifications, the individual modules can be structured to accommodate power units and fuel tanks for use as a powered causeway. The connector pieces are interchangeable and removable for rapid repairs. The modular causeway system makes it possible to transport the causeway to the amphibious operations area on a container ship or an auxiliary crane ship for rapid deployment.

4.6.2 Floating Concrete Structures.

4.6.2.1 General. Concrete floating structures have been successfully employed for some years and have been proposed for increased use in Navy piers and wharves. Where conditions make fixed structures very expensive or impractical, the floating type may become cost-effective.

4.6.2.2 Advantages of Concrete. Properly proportioned concrete (both normal weight and lightweight), when combined with prestressing, results in a dense and impermeable barrier for saltwater intrusion, ideal for keel and wall elements of the floating structure. In addition to requiring little or no maintenance, concrete provides mass to the structure, which increases the roll period and thus provides a more stable structure for operations.

4.6.2.3 Unique Requirements.

a) General. Floating structures must be operated similar to ships in that load application and ballast management must be carefully considered to avoid overstressing or sinking the structure. Stability is generally not of much concern for floating concrete structures, but heel and trim must be investigated when applying eccentric loads to the structure (i.e., lifting with cranes or storage to one side of the structure).

b) Freeboard. Freeboard requirement determines the minimum depth of the structure. As a rule of thumb, for prestressed structures, at least 45 percent of the structure will be submerged; therefore, excessive freeboard requirements will lead to a deeper, more expensive structure.

c) Compartmentalization. Compartmentalization is necessary to provide watertight buoyancy chambers and structural support to the top and bottom decks. Compartmentalization can be accomplished by a rectangular grid system of bulkheads (walls) or interlocking cylinders similar to a "honeycomb." In either case, the increase in the number of internal framing elements is directly related to an increase in cost. Therefore, the number of compartments should be limited to that required by the

American Bureau of Shipping rules for damaged stability. See American Bureau of Shipping (ABS) Rules for Building and Classing Offshore Installations - Part 1 Structures.

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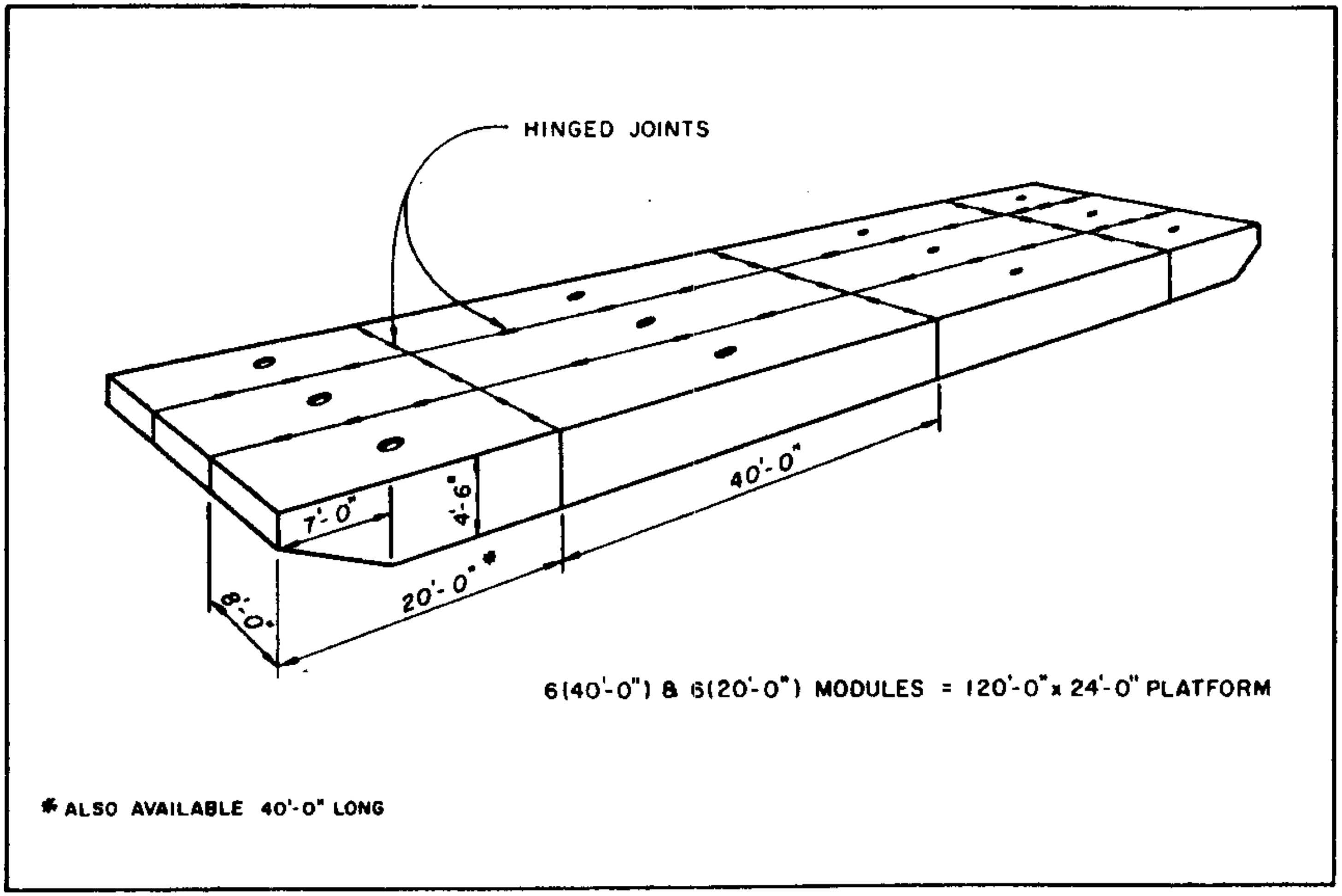

Figure 30
Container-Sized Modular Pontoons

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Special attention should be given to watertight integrity at all penetrations of bulkheads and weather decks, by using proper hatches, etc.

d) Liquid Storage. Liquid storage in the compartments should be avoided because the liquid may have a deleterious effect on the concrete and may be difficult to clean out. In addition, ventilation openings and other penetrations may be required in structural elements.

e) Waves. The floating structure is generally insensitive to waves in its operational condition because of its mass, which results in a long roll period. However, ABS requires that the structure have adequate strength to resist a delivery voyage wave which has a wave length equal to the length of the structure with a corresponding wave height and period.

4.6.2.4 Mooring Systems.

a) General. There are two basic structure anchorage systems: pile systems and mooring line systems. The selection of the appropriate mooring system is dependent on many factors, but primarily on the foundation soils. A soils investigation should be conducted to determine soil bearing capacities to support piles or anchors. Additional data required for mooring line systems include bottom contours to aid in anchor and mooring line location selection and internal angle of friction to determine size of anchors required to resist sliding. Additional data required for pile systems include uplift capacity (cohesion) and depth to point of fixity of the pile.

b) Pile Systems. Pile systems can consist of battered or plumb steel pipe piles. In general, pile systems are recommended for shallow waters and where deployment of anchors is difficult or impossible. The use of piles is limited by the soil capacities and the permissible horizontal displacement of the structure. In addition, if pile wells are required in the structure, loss of buoyancy and usable deck surface area may result. The use of plumb piles may result in unacceptable horizontal displacements of the structure. Other drawbacks to pile systems include difficulty in removing piles for possible reployment, replacing damaged piles, and providing pile corrosion protection.

c) Mooring Line Systems. Mooring line systems should be of the taut-line type. These lines have an initial tension that holds the structure in position. The effects of vertical and horizontal displacement on mooring line tension can be minimized by setting the anchors at a large distance (relative to the anticipated displacement) from the structure. Some drawbacks to mooring line systems include monitoring mooring line tension while in operation, providing corrosion protection, and irregular bottom contours and poor soil conditions which may require extensive bottom preparation.

4.6.2.5 Structural Design.

a) General. Design of the structure is separated into local and global design. The structural framing consists of prestressed flat plate elements joined together to form a compartmented box. Prestressing is highly recommended for cost-effectiveness because it reduces member thicknesses, thus saving on raw materials and reducing weight and draft.

b) Local Design. The local design of all plating elements except the top deck and the exterior wall supporting the fenders is controlled by hydrostatic loads. The critical design condition is for a hydrostatic head equal to the full depth of the structure. The top deck is designed similar to conventional structures.

c) Global Design. Loads are applied locally to the flat plate elements and then transmitted to the structure as a whole. The structure as a whole behaves as a rigid beam on an elastic foundation. All applied loads are resisted globally by equivalent uniform hydrostatic loads. The critical design loading conditions are typically deck storage and deck operational loads combined with nominal wave bending (service load capacity) and delivery voyage wave bending (cracking strength capacity check). It is necessary to check for cracking in the structure to ensure integrity for water tightness.

d) Prestressing. Prestressing is provided for strength and serviceability (i.e., prevents tension in the concrete under service loads and controls crack width under extreme loads). Watertightness at joints is also enhanced by prestressing. The minimum recommended prestress level in either direction of plate elements is 300 to 400 psi; however, specific designs may require higher prestress levels.

e) Concrete Mix. For watertightness and durability, the concrete mix used for floating concrete structures should include the following: high cement contents (typically in excess of 650 lbs/yd+3+), low water/cement ratio (typically less than 0.4), air entrainment in freezing environments, pozzolanic admixtures (silica fume or fly ash), and super-plasticizers as required to produce workable concrete.

4.6.2.6 Fender Systems.

~~a) General.~~ Reaction input to the pier structure is a critical performance parameter for fender systems. High reactions may require stiffening of the exterior plating of the pier structure or the location of additional internal framing to support the fender loads, thus adding cost to the pier structure. Three types of fenders are recommended: foam-filled, buckling cell, and delta. Sufficient ~~overcapacity~~ additional capacity above the calculated design energy should be provided to resist extreme berthing energy so as to avoid puncturing the external plating. For additional criteria, see Section 5, Fender Systems.

~~b) Foam-Filled Fenders. Foam-filled fenders provide large energy absorption capacity with relatively small reaction input to the pier~~

~~structure, with the added benefit that they can be easily relocated along the face of the pier structure. These fenders may not require any special stiffening of the external plating.~~

~~c) Buckling Cell Fenders. Buckling cell type fenders provide large energy absorption capacity with relatively small reaction input to the pier structure. These fenders can be mounted directly on the external plating or at specially designated hard spots.~~

~~d) Delta Fenders. Delta type fenders provide large energy absorption capacity but with larger reaction input to the pier structure than the previous systems. These fenders can be mounted directly on the external plating but would require additional stiffening or buttresses to transfer the reaction into the structure.~~

4.7 Mooring Hardware.

4.7.1 General. Ships are usually moored to bollards, bitts, and cleats. Occasionally, ships may be tied to a quick-release hook. The position of a ship on a berth is usually controlled by utility hookup and brow location requirements. The crew in charge of tying up the ship will usually tie the lines to whatever mooring hardware is convenient to give the required horizontal angle. This often results in lines tied to a lower capacity cleat while a high-capacity bollard may only be a few feet away. Hence, consideration should be given to using only one type of high-capacity mooring hardware throughout the facility. When possible this mooring hardware should be sized for the maximum size vessel that could possibly use the facility. Hardware should be spaced to maximize the berth flexibility for use by ships other than the specific vessel the berth was designed to accommodate. In addition, mooring hardware requirements will depend on the mooring service type assigned to the berth as defined in MIL-HDBK 1026/4. For mooring service types III and IV, consideration should be given to providing additional heavy weather mooring hardware. The desire to provide the higher capacity hardware must be balanced with the cost constraints in that the higher strength hardware and supporting structure will cost more. The geometry of the hardware should preclude mooring lines from slipping off, as the mooring angle is often very steep.

4.7.2 Hardware Types. The following are the most commonly used types of mooring hardware:

4.7.2.1 Bollards. A bollard (Figure 31) is a short single-column cast steel fitting that extends up from a baseplate that is secured to a strong point of a shore structure or berthing facility. Bollards are used in snubbing or checking the motion of a ship being moored, by tightening and loosening mooring lines that are fastened to them. Bollards are also used for securing a ship that has been placed in its final moored position. Bollards without ears should not be used in facilities where a high vertical angle of the mooring line is anticipated, to prevent lines from slipping off.

4.7.2.2 Bitts. Bitts (Figure 31) are short, double-column, cast-steel fittings fastened to the deck of berthing facilities. They are used to snub and secure a vessel. The double columns allow for convenient and rapid tying and releasing of mooring lines, as well as for guiding a line through to other hardware.

4.7.2.3 Cleats. Currently, available cleats (Figure 32) are low-capacity cast steel deck fittings having two projecting arms that are intended to be used for securing mooring lines of small craft. They are provided at most naval facilities. Given a choice, line handling crews will use cleats in preference to bollards or bitts, even for large ships, as the possibility of line slippage is remote. However, cleats can easily be overloaded when they are used in lieu of major fittings such as bollards~~ for securing heavy mooring lines~~. Because of

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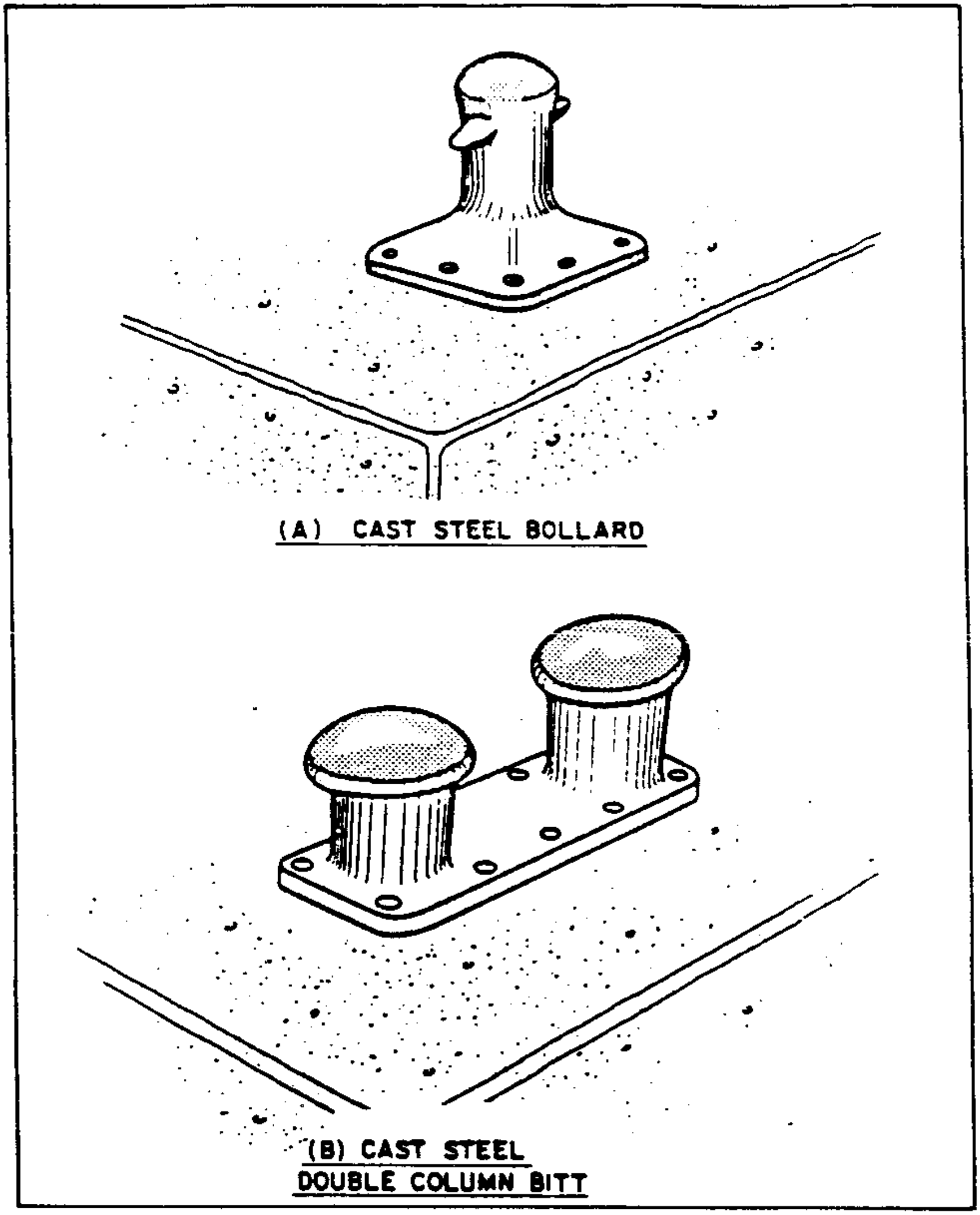

Figure 31
Bollard and Bitt

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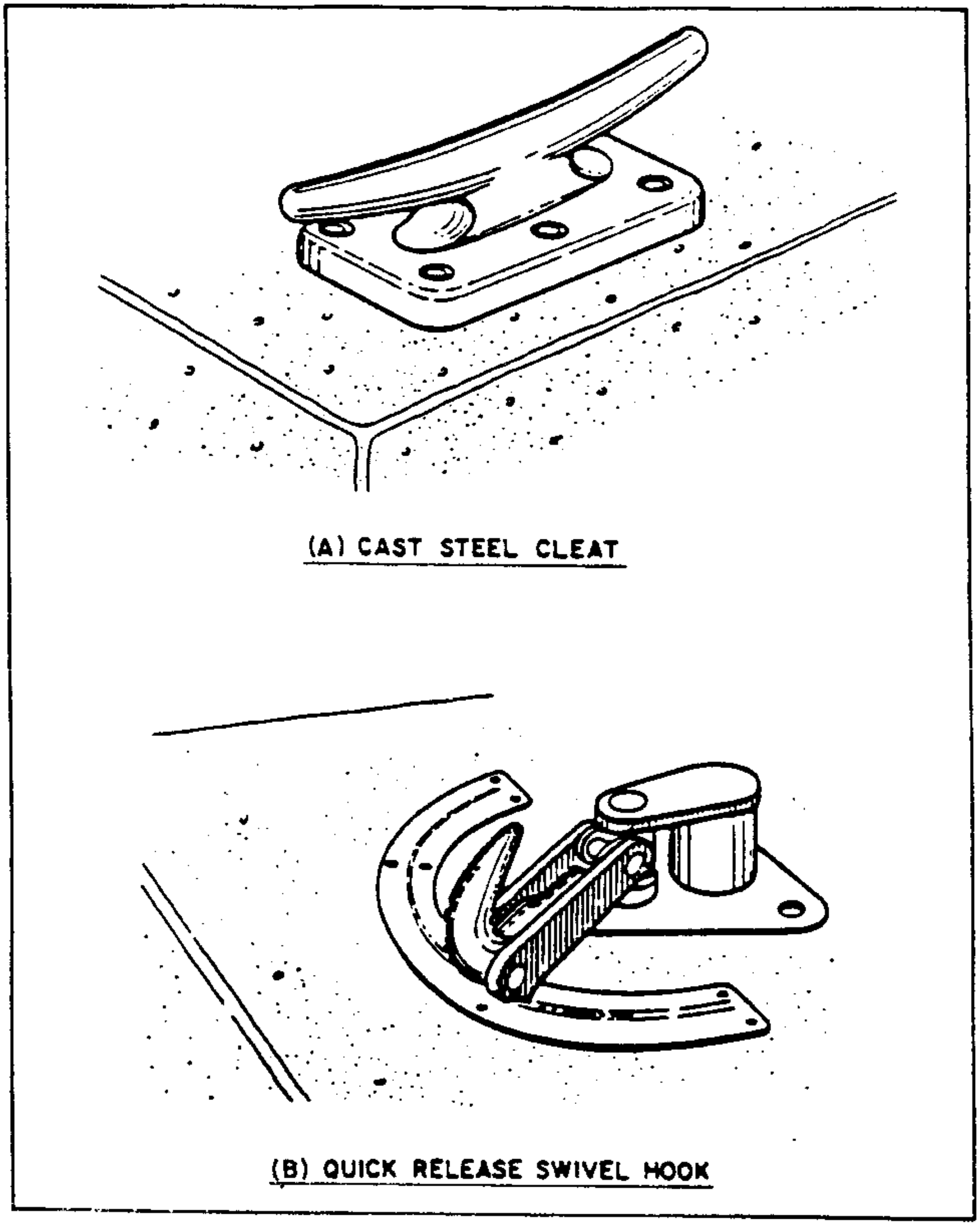

Figure 32
Cleat and Quick-Release Hook

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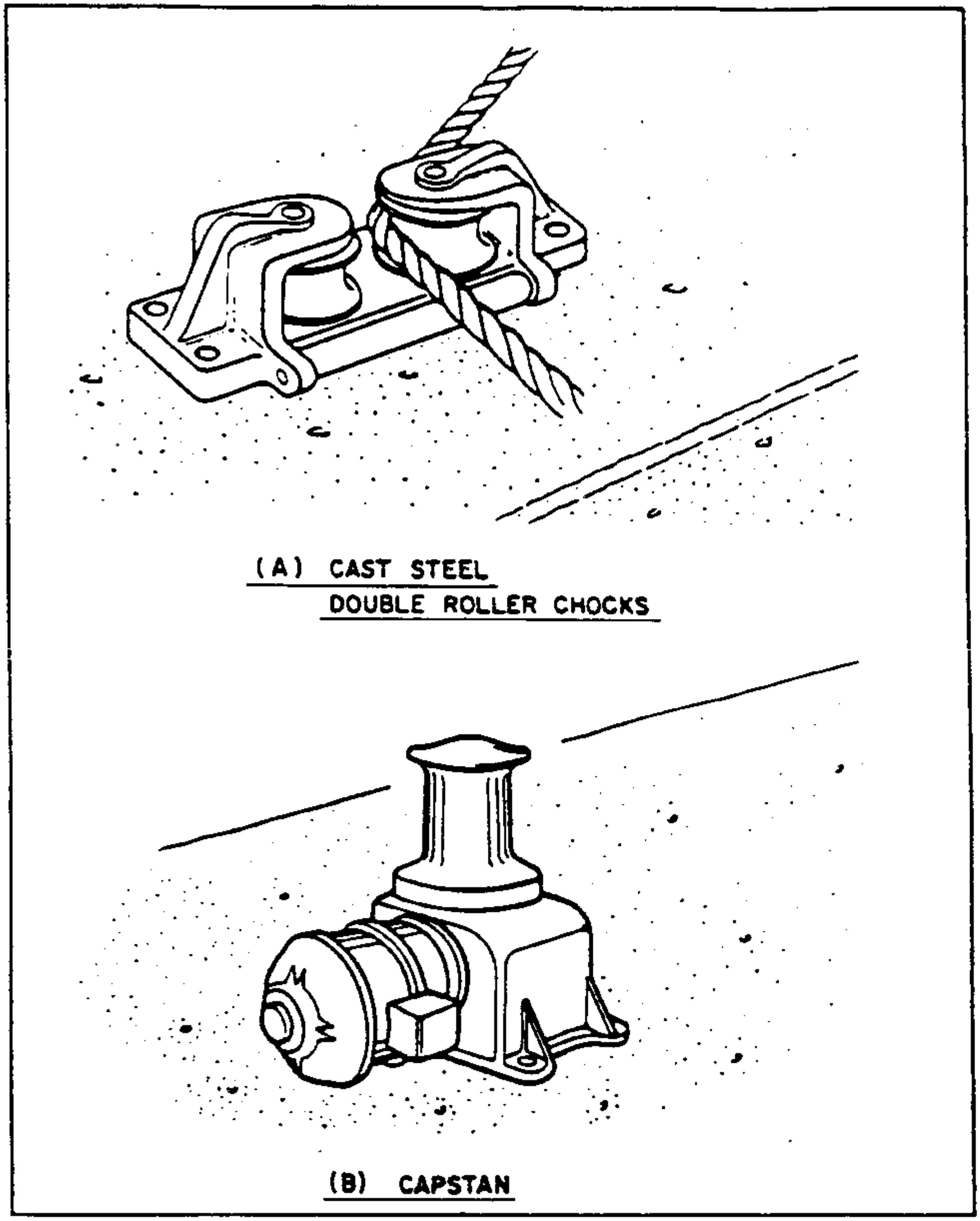

Figure 33
Chock and Capstan

the low holding capacity of cleats, they should not be used in combination with higher capacity deck fittings.

4.7.2.4 Chocks. Chocks are either stationary or roller-equipped cast deck fittings that are used to train the direction of a mooring line. Chocks are available either open at the top, permanently closed, or closed by a hinged closing piece. See Figure 33.

4.7.2.5 Capstans. Ships outfitted with winch-mounted wire rope mooring lines require greater pulling power than can be provided by one or two deck hands to draw out the ship's lines. The assignment is handled by capstans that are mounted along the face of the wharf. The capstans are small electric winches of 5 to 10 hp with a drum rotating about a vertical axis. The capstan is used by a deck hand who receives a messenger line at the end of which is fastened the sling of the wire rope hawser. The capstan, receiving several winds of the messenger line, provides the pulling power needed to draw out the wire rope hawser. The messenger line is then returned to the ship. Capstans are also used as primary guidance (breasting and in-haul) to berth ships in drydocks and slip-type berths (Trident facilities). For these uses, the capstans are of larger capacity and are typically two-speed. See Figure 33.

4.7.2.6 Quick-Release Hooks. The quick-release hook (Figure 32), generally mounted on a swivel base, is a deck fitting used to receive mooring lines. When a ship is required to make a hasty departure from its berth, a tug on the hook's release mechanism unfastens the mooring line. The mechanism can also be tripped from the ship when a tag line is provided. Thus, a ship can made a sudden departure without the assistance of shore personnel. Quick-release mooring hooks with integral power capstans are necessary for securing the steel mooring lines on petroleum tankers at fuel piers, while bollards are needed for the supplementary lines other than steel.

4.7.3 Strength. The required strength of mooring hardware and its fastenings is determined by the breaking strength of the strongest mooring line or lines that may be fastened to it. Mooring hardware can and does receive more than one line and as many as three are not unusual. Because it is unlikely that three lines fastened to one hardware are equally tensioned and each pulling in the same direction, the design criteria generally consist of the application of a force equal to one and one half to two times the breaking strength of the strongest mooring line anticipated. The sizes of mooring lines are limited to those that can be conveniently handled by deck hands. Thus, wire rope lines generally do not exceed 1-3/4-in. diameter.
~~The following minimum strengths should be available from the mooring hardware and its anchorage system, with the loads applied along angles (up to 60 deg. from horizontal) and all the horizontal directions:~~ Some of the fittings commonly used on U.S. Navy pier and wharves are summarized in Table 6.

~~Bollards, double bitts, and quick-release hooks ..... 100 tons~~
~~Storm bollards (refer to Section 3) .... 200 tons~~
~~Cleats .... 20 tons~~
~~Capstans .... 50 tons~~

Table 6
Mooring Fittings

DESCRIPTION	SIZE	BOLTS	WORKING CAPACITY (tons)
Special Mooring Bollard "A"	Height = 48 in. Base: 48x48 in.	12 x 1-in. dia.	Horiz. = 330 @45 deg = 215 Nom. = 225
Special Mooring Bollard "B"	Height = 44.5 in. Base: 39x39 in.	8 x 2.25-in. dia.	Horiz. = 135 @45 deg = 108 Nom. = 100
Large bollard with Horn	Height = 44.5 in. Base: 39x39 in.	4 x 1.75-in. dia.	Horiz. = 52 @45 deg = 33 Nom. = 35
Large Double Bitt with Lip	Height = 26 in. Base: 73.5x28 in.	10 x 1.75-in. dia.	Nom. = 37.5*
Low Double Bitt with lip	Height = 18 in. Base: 57.5x21.5 in.	10 x 1.625-in. dia.	Nom. = 30*
42-inch Cleat	Height = 13 in. Base: 26x14.25 in.	6 x 1.125-in. dia.	Nom. = 20
30-inch Cleat	Height = 13 in. Base: 16x16 in.	4 x 1.125-in. dia.	Nom. = 10

*Working capacity per barrel: after NAVFAC Drawing No. 1404464

4.7.4 Placement. If a berthing facility were always to receive the same class of ship, each of which had identical arrangements for putting out mooring lines, a specific pattern for mooring hardware spacing, based on the ship's fittings, would be satisfactory. Most naval berthing facilities require a high degree of flexibility in order to be able to receive several types and sizes of ships. Therefore, a universal pattern for mooring hardware spacing is preferred. Mooring hardware spaced at 60 ft on centers along the berthing face of a structure will, in most instances, provide the number of fittings required to secure the ships during the periods of time that wind velocities and conditions of sea do not exceed the design criteria established for ~~the facility~~mooring service types I and II. Mooring service types III and IV will likely require additional high capacity storm bollards which are normally set back at least 100 feet from the face of the berth to provide a shalloow line angle.

a) A berthing facility that will accommodate ships having large wind presentments, such as aircraft carriers, should be outfitted with ~~supplemental~~ 12 – 100 ton bollards ~~for use when periods of high winds are forecast~~at 100 foot centers and 4 – 200 ton storm bollards at each end. The ~~supplemental bollards and~~ storm bollards, which would be used to secure ~~normal~~ breasting lines, should be located inshore from the face of the wharf, thus reducing vertical angles and permitting the use of longer (safer) mooring lines. ~~Bollards should also be provided at ends of all piers and wharves and, if necessary, should be supported on a mooring dolphin to yield a more convenient horizontal angle.~~

b) At submarine berths where mooring lines go down to the submarine, the mooring hardware should be located as close as possible to the waterside edge of the bullrail to minimize chafing of the lines. Where this is not feasible, a continuous smooth member such as a bent plate should be cast in the concrete bullrail, as shown in Figure 34.

4.8 Mooring Dolphins/Platforms.

4.8.1 General. Mooring dolphins are ~~small~~ independent structures constructed at one or both ends of a wharf (or outboard end of a pier) to provide a more favorable angle to the mooring lines. The dolphin is accessed by a walkway from the pier or wharf end. Typically, the mooring line from the ship is carried on the walkway and attached to mooring hardware mounted on top of the dolphin.

4.8.2 Design. The primary load for a mooring dolphin comes from the tension in the mooring line. It is typically constructed as an open pile supported structure. Where filled (solid) construction is permitted, a single sheet pile cell may be utilized. When a platform is provided for the dolphin, it should be large enough to allow a 3-foot-wide walking space all around the mooring hardware.

4.8.3 Construction. Timber mooring dolphin~~e~~s can be constructed from 7, 19, or 37 wood piles with a king pile in the center and other piles arranged in a circular pattern around the king pile. A 19-pile dolphin is illustrated in Figure 35(A). ~~Depending on the pull-out resistance available from the subsoil, timber dolphins may be designed for up to 100 kips of lateral load.~~ The use of timber dolphins should be limited to facilities not requiring high capacity mooring points. Timber dolphins may be required for magnetic sensitive facilities. In areas with ready access to timber piles, timber dolphins may be popular for small craft, tugs, patrol craft and barges. For higher loads, a concrete dolphin is preferred, which is illustrated in Figure 35(B). Because both timber and concrete dolphins can be expected to move significantly (1 to 6 in.) from the lateral load, the access walkway should be designed and detailed to allow for this movement.

4.9 Miscellaneous Considerations.

4.9.1 Expansion Joints. ~~Since~~Because expansion joints require frequent maintenance for proper functioning, piers and wharves should use as few joints as possible. The size and number will depend on the temperature range and structural system employed. Expansion joints should be provided at the junction of an approach with the main structure and such other places where there is a major structural discontinuity. Provide additional expansion joints where necessary to limit buildup of thermal loads. (See Section 3, paragraph 3.~~3~~4.6, Thermal Loads.) For recommended types of expansion joints, see ~~NAVFAC DM-25.06~~MIL-HDBK 1025/6. The joint should be continued through railroad tracks and crane rail tracks. Recommended details are shown in Figures 36 and 37. Likewise, utilities crossing expansion joints should be detailed to accommodate the expected longitudinal and lateral movements.

4.9.2 Drainage. Pier and wharf decks should be sloped in transverse and longitudinal direction to deck drains or scuppers to provide for drainage of storm water. Where permitted, the storm water can be drained off to the water below; however, if fuel, oils, and chemicals are to be handled on the facility, the storm water should be collected and piped off for treatment. A complete review of local jurisdictional requirements for storm water management and treatment is required for each facility may vary significantly between locations. It is customary to use subsurface drains in ballasted decks to handle any small amounts

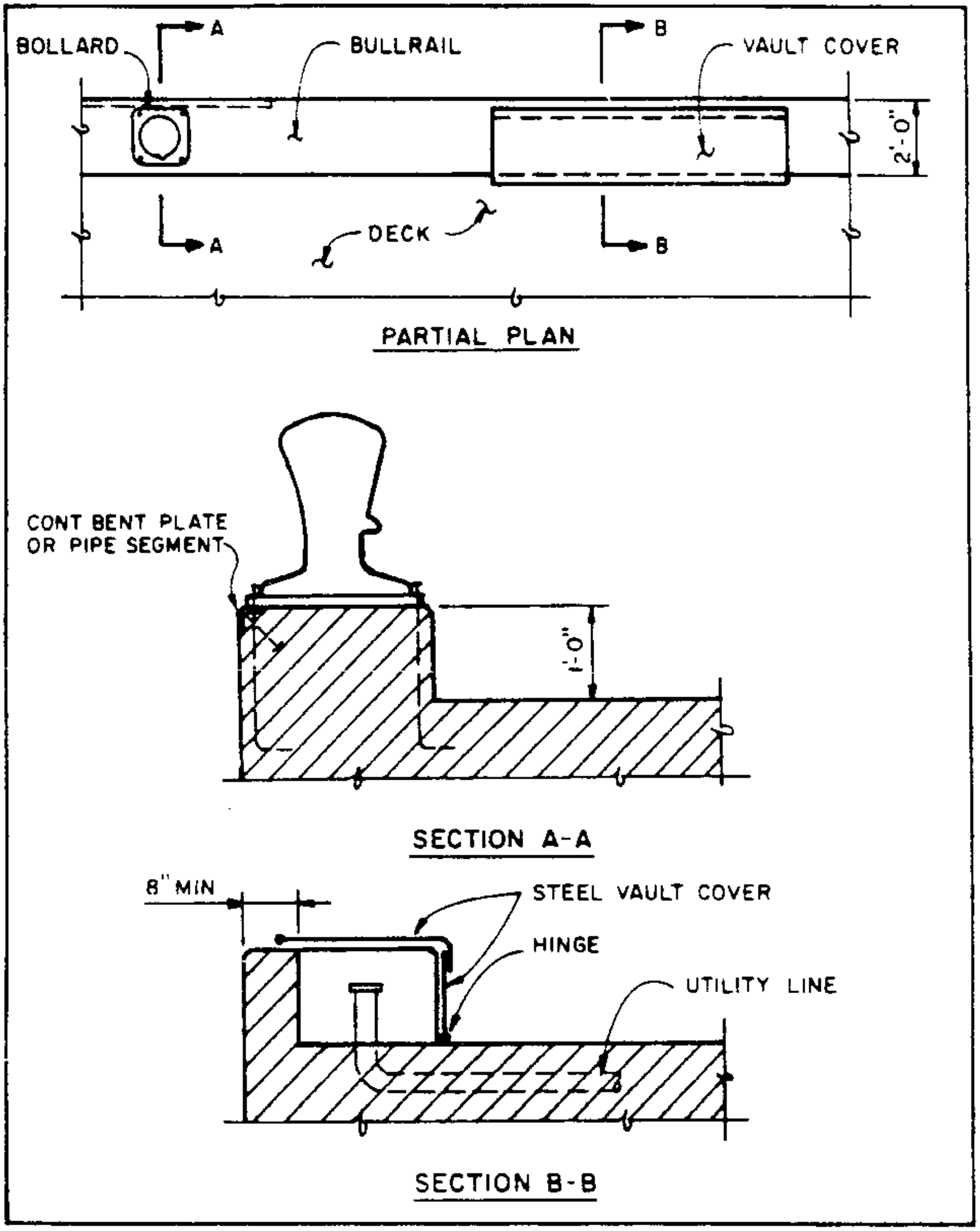

Figure 34
Bullrail Details

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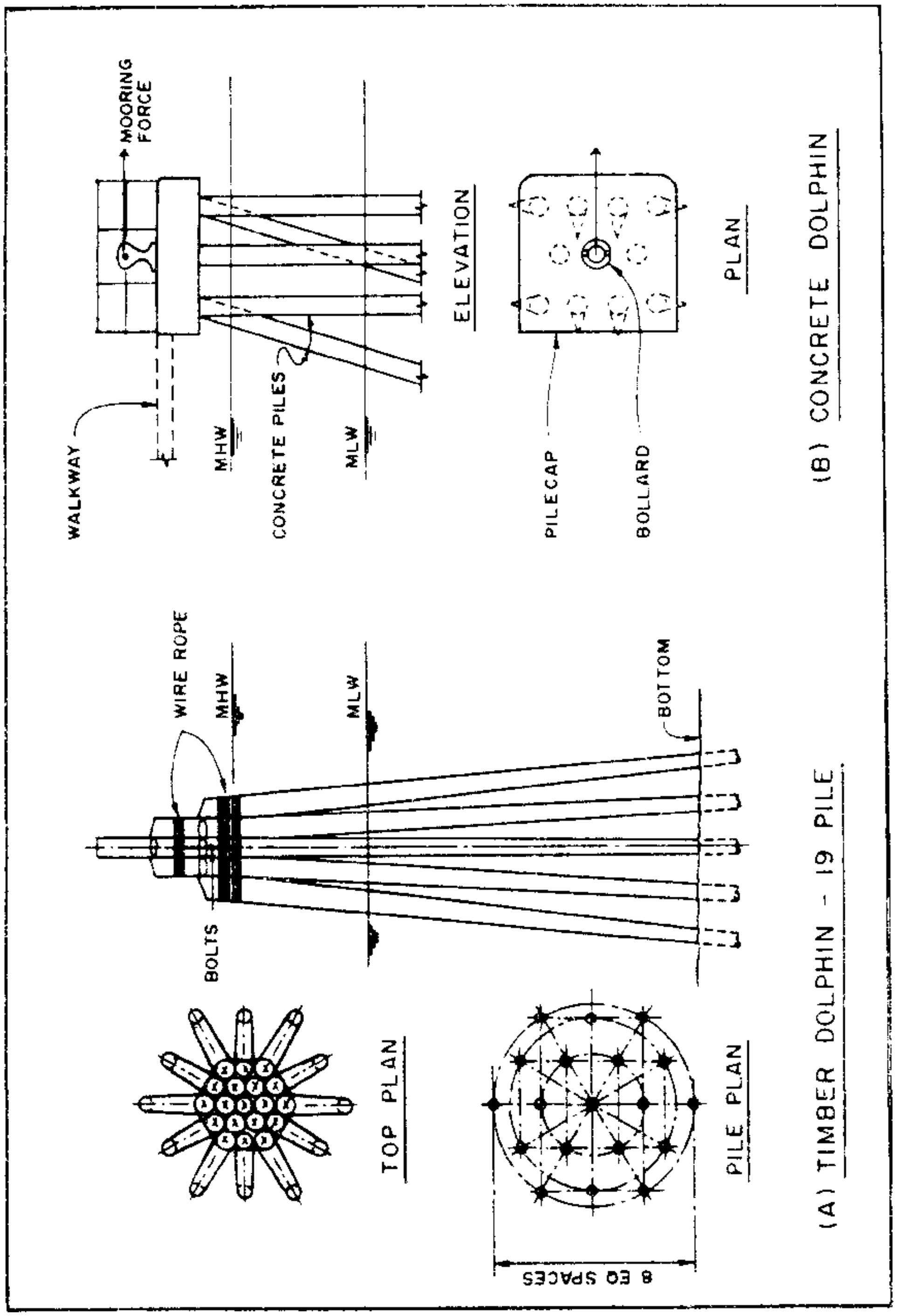

Figure 35
Mooring Dolphins

of water that may seep through the paving. This water is normally not collected.

4.9.3 Bullrail. On all waterside edges of piers and wharves, a curb or bullrail ~~at least~~9 to 12 in. high by ~~18~~ 12 to 24 in. wide should be provided. Some mooring hardware may be accommodated within the 24-in. width, thus permitting a clear inside face for easy snow removal and line handling. As shown in Figure 34, it is also generally possible to house utility vaults within the width of the bullrail. The bullrail should be sufficiently reinforced and anchored to the deck structure. When a continuous bullrail is available, it may be reinforced to serve as chord member for a structural diaphragm.

4.9.4 Utility Trench. ~~Since~~ Because the utility services are mostly needed along the pier or wharf edge, the main utility trenches should be kept close to the bullrail. The trench may be underhung or kept above, as shown in Figure 38. The trench covers should be removable and made of concrete, steel, or composite construction. Although the trench covers need not be watertight, a good seal should be used at joints to prevent accidental seepage of spilled liquids. Frequently spaced drains should be placed along the trench to prevent flooding. Adequate width and depth need to be provided to allow access for maintenance of utilities.

4.9.5 Transformer Vaults. When a clear deck is required for operations, the electrical transformers and switchgear may be housed in underhung vaults, as shown in Figure 39. The vaults must be constructed watertight and provided with sumps and pumps for quick removal of leaked water. The vault covers should be removable. The joints between vault and cover should be watertight. ~~Since~~ Because the continued functioning of the transformers is critical to the facility operation, a separate roof system should be employed just below the removable covers to serve as a second line of defense against joint leaks.

4.9.6 Utility Hoods. Connection points or "utility risers" projecting above deck or bullrail should be protected from snagging of mooring lines by pipe rails or concrete hoods, as shown in Figure 40. Alternatively, when the bullrail is wide enough, hinged utility covers like the one shown in Figure 34 may be employed. For convenience of the users, the risers should not face away from the ship, and should be adequately sized for ease of operation.

4.9.7 Deck Markings. All berths and utility stations should be marked as illustrated in Figure 41. In addition, centerlines of all structural bents and load capacities of all mooring hardware should be painted on the bullrail.

4.9.8 Wearing Course. Generally, a wearing course is not needed for concrete deck structure. However, for precast concrete decks, an asphalt concrete or cement concrete wearing surface may be utilized to provide a slope for drainage. For ballasted decks and for solid (filled) type construction, a wearing course is necessary. For these applications, asphaltic concrete is preferred over cement concrete as the former is easier to repair and maintain and better tolerates substrate movement.

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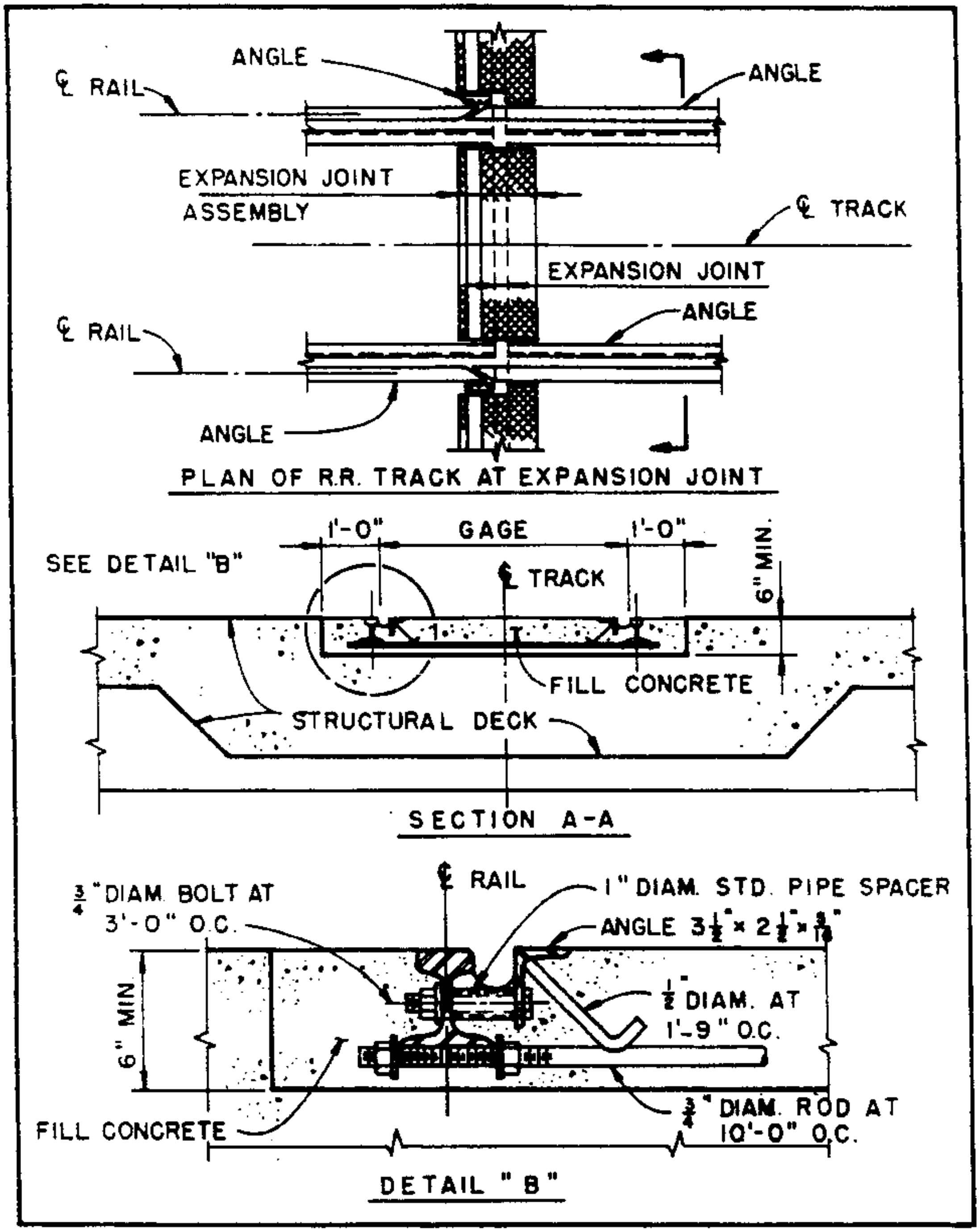

Figure 36
Railroad Track Support

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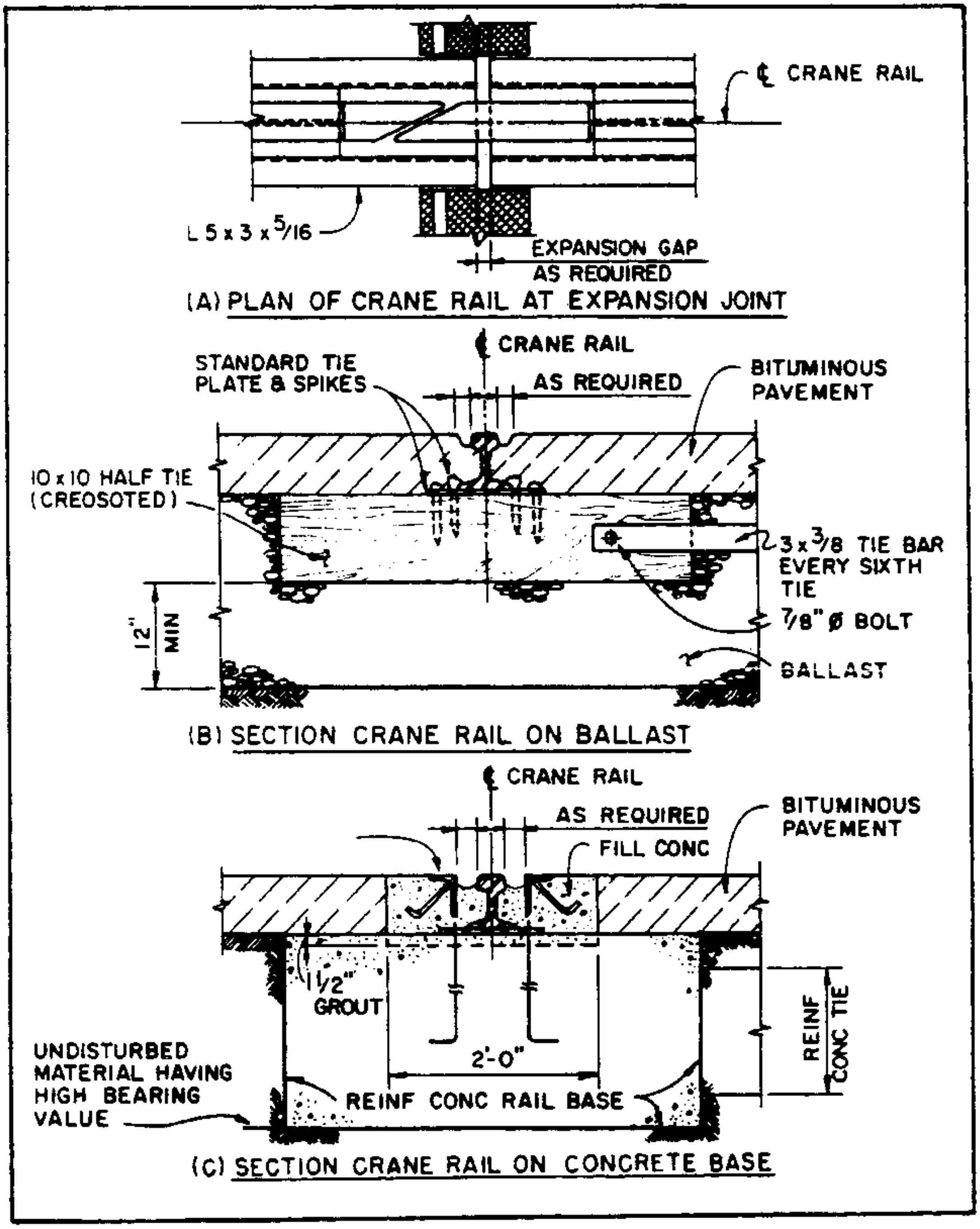

Figure 37
Crane Rail Support

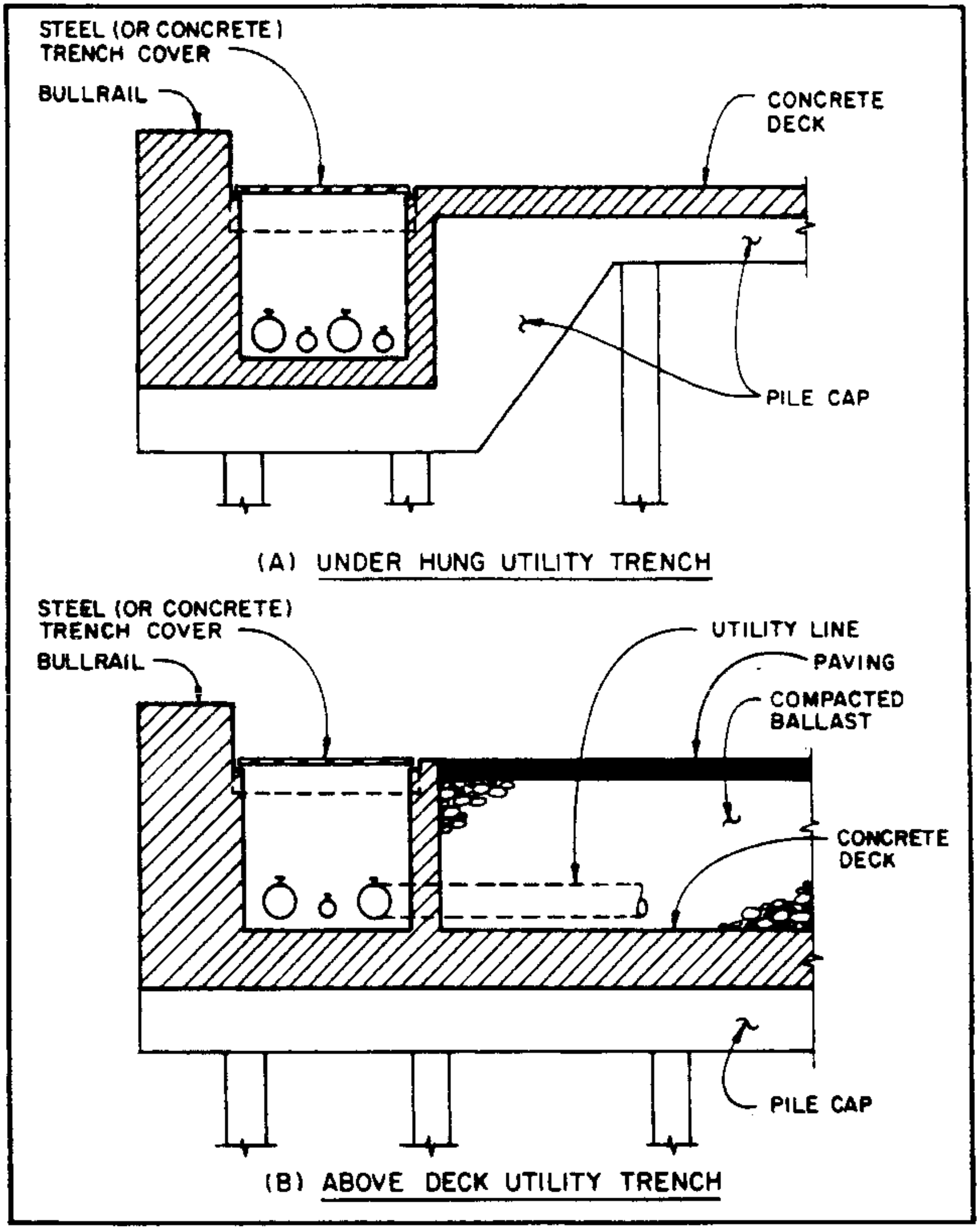

Figure 38
Utility Trench Concept

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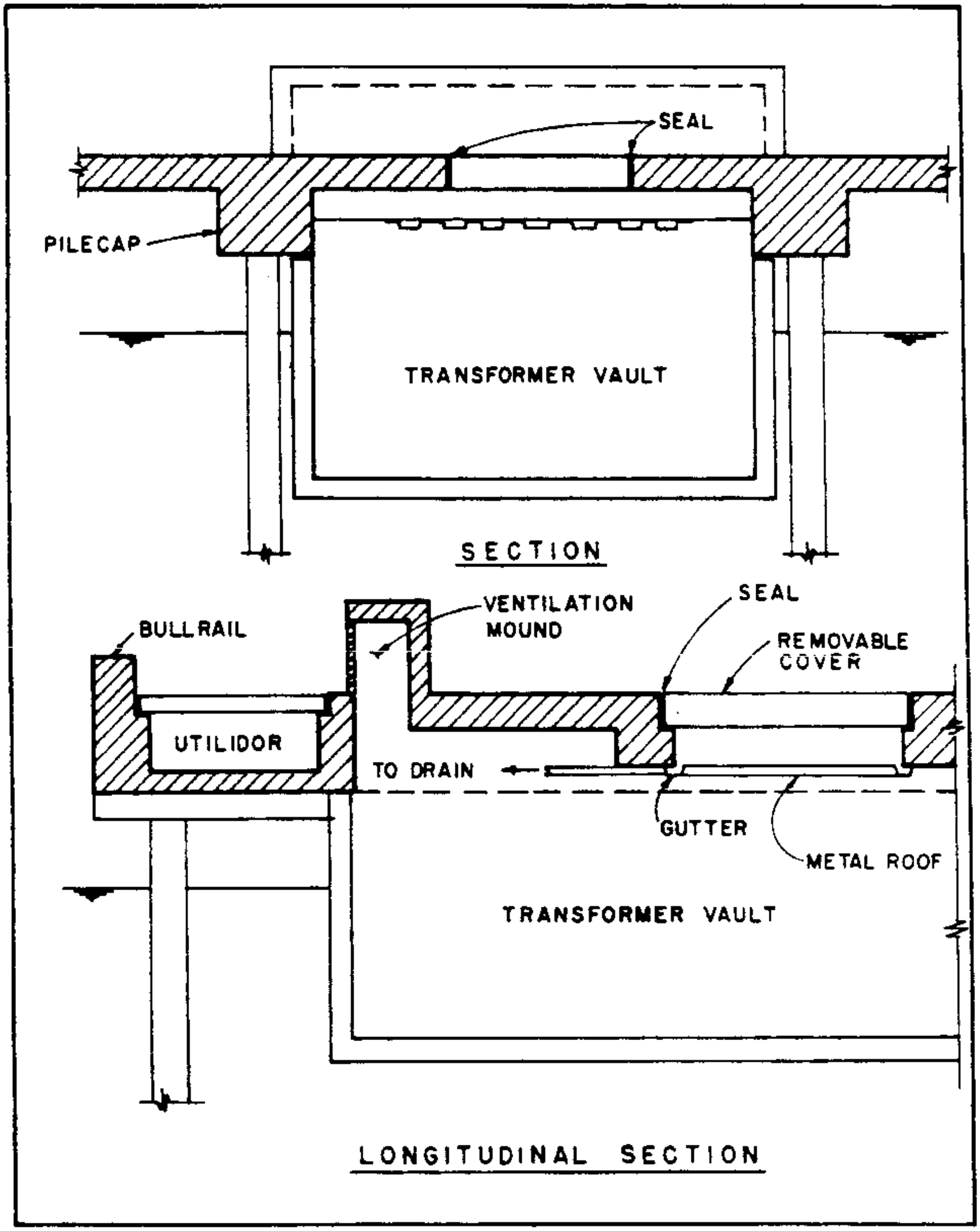

Figure 39
Transformer Vault

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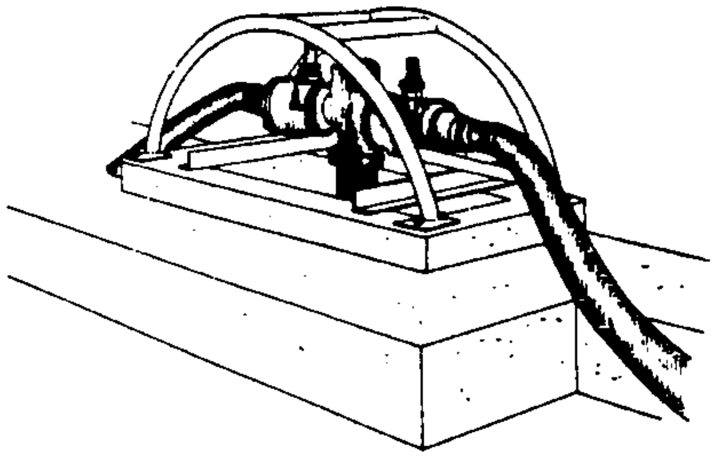
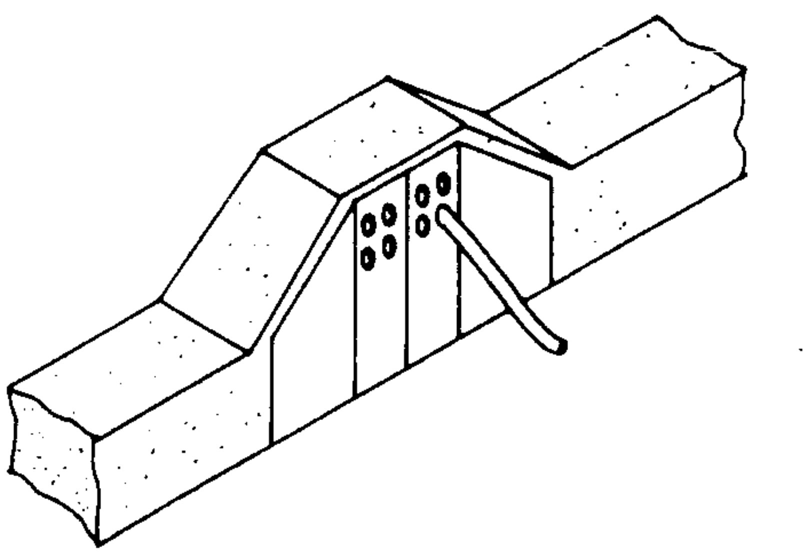


(A) STEEL ROPE GUARD OVER VALVE STATION



(B) CONCRETE ROPE GUARD OVER ELECTRICAL BOX

Figure 40
Utility Hoods

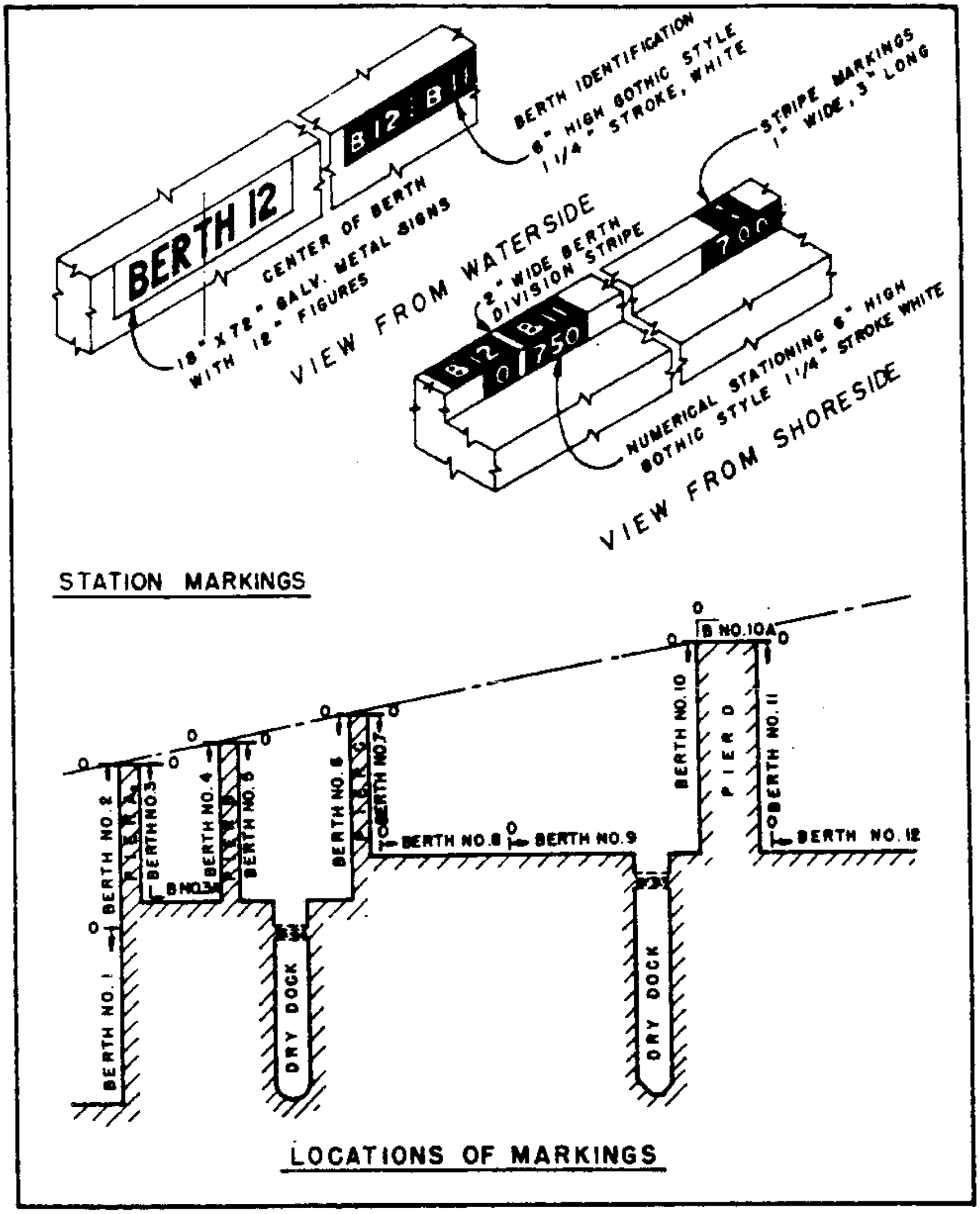


Figure 41
Layout of Berth and Station Markings

Section 5. FENDER SYSTEMS

5.1 General Considerations

5.1.1 General. The fender system is the interface between the ship and the shore facility. During the berthing of a ship, the fender system is meant to act as a buffer in absorbing or dissipating the impact energy of the ship without causing permanent damage to the ship or the shore facility. Where ships are to be berthed against relatively inflexible solid piers and wharves, protection of the ship is a critical function. When ships are to be berthed against pile-supported piers, wharves, and dolphins (which are relatively flexible), protection of the structure ~~is~~ may be the more serious concern. Once the ship is successfully berthed and moored to the shore facility, the fender system continues to provide the interface between ship and shore and transmits the environmental loads (wind, waves, and current) on the ship to the structure. For submarine and other low-profile ship berthing, the fender system also provides a physical barrier to prevent the vessel from going underneath the pier and causing a major accident.

5.1.2 Berthing Practice. The selection and design of a fender system is highly dependent on the berthing practice employed at the particular naval facility. Typically, large ships are expected to be brought into the berth assisted by two or more tug boats. Smaller ships in some locations may be allowed to come in on their own power. When assisted by tugs, the ship would arrive off the berth and parallel to it. The ship then stops dead in the water and the tugs push and pull the ship transversely toward the berth in an attempt to make contact with as much of the fender system as possible. When unassisted by tugs, the smaller ship will be eased into its berth at some slight angle, referred to as the angle of approach. In both cases, the initial contact is limited to a relatively small portion of the fender system. Assumptions will have to be made regarding the approach angle and contact length.

5.1.3 Separators. Because of the many reasons explained in Section 6, most Navy ships are berthed against separators. This practice is the most significant difference between commercial ship berthing and naval ship berthing. For aircraft carrier and submarine berthing, separators are mandatory. For surface combatant berthing, even though separators are not needed, they are preferred to direct the berthing forces at the waterline (where the ship is strongest). Berthing against separators, which are usually floating camels, concentrates the impact energy to a small length of the fender system as well as applies the energy at some distance below the deck. This aspect must be recognized in all fender system design for Navy ships. A fender system designed for commercial ships will, in general, not be satisfactory for naval applications. **The practice of using camels has resulted in a general trend for a minimum of hull protrusions near the waterline. Fender systems with higher fender contact** area **are more susceptible to damage from longitudinal movement of the vessel due to snags.**

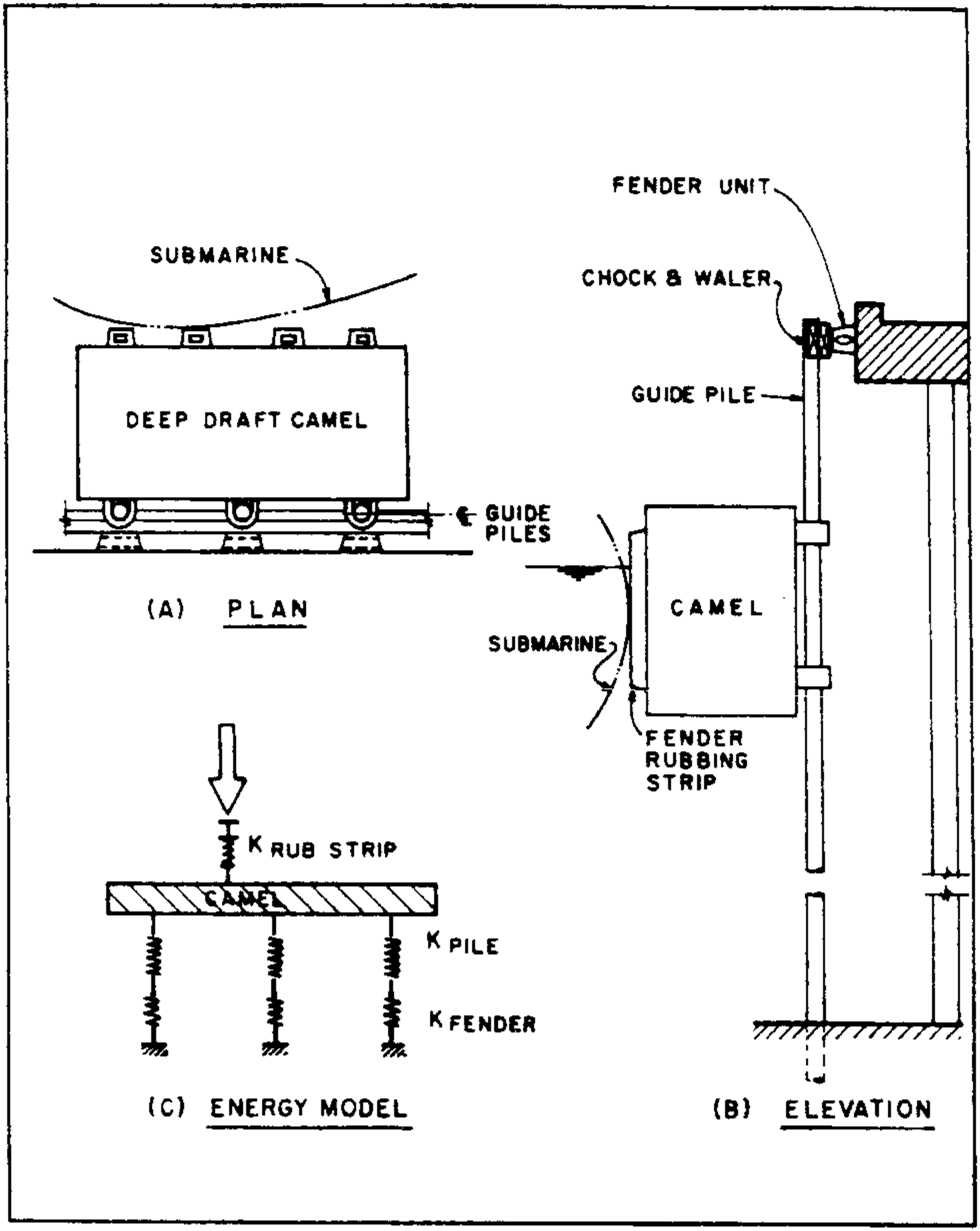


Figure 42
Energy Model of a Fender System

5.1.4 Systems Approach. The impact energy of the berthing ship is absorbed in a complex system of interconnected elements. For the system shown in Figure 42, the load passes from the ship's hull to the separator, which is backed by a series of fender piles. The fender piles in turn are supported by rubber fender units at the deck level. The ship's energy in this case is absorbed by the ship's hull, rubbing strips, separator, fender piles, and rubber fenders at deck level. The system can be modeled as shown in Figure 42(C). The energy absorbed and the force developed by each element can only be solved by an iterative process.

5.1.5 Functional Requirements.

5.1.5.1 Energy Absorption. All fender systems should be designed for absorption of the ship's berthing energy in all the structural types of piers and wharves.

5.1.5.2 Separators. All piers and wharves should be designed for berthing with camels and other separators. To provide berthing flexibility and to allow for the requirements of ship maintenance, the entire berth length should be suitable for the placement of separators.

5.1.5.3 Normal Berthing. The fender system should be able to absorb the energy from normal berthing operations within the working stress or acceptable deformation range as defined in this section. Some manufacturers indicate a load deflection curve tolerance of plus or minus 10%. If this is determined to be the case, the design reaction on the structure should be increased by 10% and the energy absorption for design should be decreased by 10%. Variations in the speed of testing of fenders may affect the resulting load-deflection curves. Where the test loads are applied rapidly, i.e., at a speed comparable to the actual ship berthing, the load-deflection will indicate higher reaction and energy than if the test load is applied slowly. Therefor, care should be taken when comparing test results from different manufacturers, and appropriate adjustments should be made in the factors of safety used in design. Differences of in the order of 30% can be expected.

5.1.5.4 Accidental Berthing. ~~Since~~Because the fender system is less expensive than the ship or the berthing structure, some damage to it may be permissible and acceptable. So, in the event of an accidental situation, it is the fender system that should be "sacrificed." Loss of the berth has a much more serious consequence than loss of part or all of the fender system in terms of the cost and time required to restore the facility. The cost and time to repair a damaged ship is of much greater concern than the berth and the fender system. The accidental condition may be caused by increased approach angle or approach velocity or a unique situation that cannot be anticipated. In the absence of any other accident scenario, the berthing energy as calculated in this section should be increased by at least 50 percent and the fender system should be capable of providing this "reserve" capacity at or near failure of the system materials.

5.1.5.5 Moored Condition. All fender systems selected should be capable of safely transferring the environmental loads on the ship to the mooring structure.

5.1.5.6 Hull Damage. All fender systems should be designed to prevent permanent deformation of the ship's hull. It is much more expensive to repair a ship's hull than rehabilitate a damaged fender system. The composition of a typical Navy hull is steel plating welded to longitudinal (horizontal) stiffeners at two to four feet on center. The stiffeners span from five to twenty feet depending on the vessel. Generally, the stiffeners are of sufficient strength to preclude failure from fender loading. However, the hull plating may yield when subjected to a uniformly distributed overload on the panel. Fender systems with rigid face elements or in combination with rigid camels tend to concentrate the reaction forces on the ships frames versus the hull plating due to the relative stiffness of the frames. See TR-6015-OCN, "Foam Filled Fender Design to Prevent Hull Damage", for additional information.

5.2 Berthing Energy Determination.

5.2.1 Methods. The following methods can be used in the determination of berthing energy of the ship.

a) Kinetic Method. The kinetic method is the oldest and so far the most commonly used approach. It is based on the expression

EQUATION: $E = \frac{1}{2} Mv^2$ (2)

where

E = Energy of ship at berthing

M = Mass or the water displacement of the berthing ship

v = The approach velocity of the ship at the moment of impact against the fender

b) Statistical Method. This method is based on actual measurements of the energy of the impact at existing berths. This method is closely related to the conditions of the site where the measurements were taken and is dependent on the fender layout and construction itself as, e.g., distance between piles, and of the state of loading of the ship.

c) Scale Model. This method, which makes use of a small scale model test of the berth to be designed in a well-equipped hydraulic laboratory or ship model basin, suffers from the scale and viscosity effects and requires experienced interpretation.

d) Mathematical Model. The Naval Facilities Engineering Service Center (NFESC) has developed an analytical model which can accurately predict ship berthing impact forces. The model employs a computational fluid mechanics approach, coupling a Reynolds-Averaged Navier-Stokes (RANS) numerical method with a six-degree-of-freedom motion program for time-domain simulation of ship and fender reactions. The model has been verified with data from small scale and full scale tests ~~This method is still under development and comparison with full-scale berthings is not (yet) available.~~

5.2.2 Kinetic Method. The kinetic energy method is the recommended method for piers and wharves of naval facilities. When the displacement tonnage of the ship is known, the energy equation can be written as

EQUATION: $E_{ship} = ½Wv^2/g$ (3)

where

E_{ship} = Berthing energy of ship (ft-lbs)

W = Weight of the ship in pounds

(displacement tonnage x 2,240)

g = Acceleration due to gravity (32.2 ft/second^2)

v = Berthing velocity normal to the berth (ft/second)

However, there are several factors that modify the actual energy to be absorbed by the fender system. The expression can be written as

EQUATION: $E_{fender} = C_b \times C_m \times E_{ship}$ (4)

where

E_{fender} = Energy to be absorbed by the fender system

C_b = Berthing coefficient = $C_e \times C_g \times C_d \times C_c$

C_m = Effective mass or virtual mass coefficient

Each of these coefficients is discussed separately below.

a) Eccentricity Coefficient (C_e). During the berthing maneuver, when the ship is not exactly parallel to the berthing line, not all the kinetic energy of the ship will be transmitted to the fenders. Due to the reaction from the fender, the ship will start to rotate around the contact point, thus dissipating part of its energy. Treating the ship as a rigid rod of negligible width in the analysis of the energy of impact on the fenders leads to the simple formula:

EQUATION: $C_e = k^2/(a^2 + k^2)$ (5)

where

k = Radius of longitudinal gyration of the ship in ft

a = Distance between the ship's center of gravity and the point of contact on the ship's side, projected onto the ship's longitudinal axis in ft

Values of C_e typically are between 0.4 and 0.7. The values for C_e may be computed from Figure 43.

b) Geometric Coefficient (C_g). The geometric coefficient, C_g, depends upon the geometric configuration of the ship at the point of impact. It varies from 0.85 for an increasing convex curvature to 1.25 for concave curvature. Generally, 0.95 is

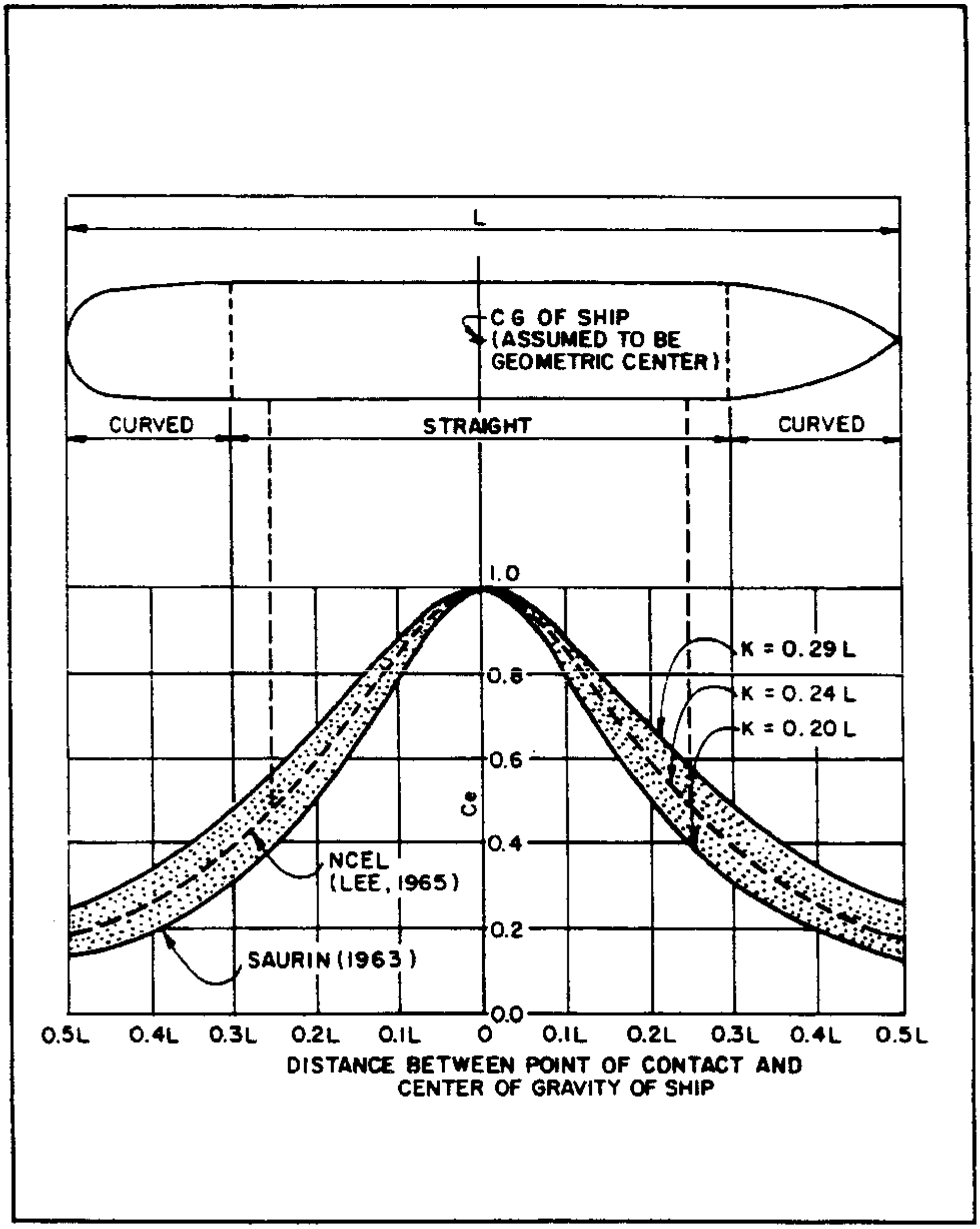


Figure 43
Eccentricity Coefficient, C_e

ended for the impact point at or beyond the quarter points of the ship, and 1.0 for broadside berthing in which contact is made along the straight side.

c) Deformation Coefficient (C_d). This accounts for the energy reduction effects due to local deformation of the ship's hull and deflection of the whole ship along its longitudinal axis. The energy absorbed by the ship depends on the relative stiffness of the ship and the obstruction. The deformation coefficient varies from 0.9 for a non-resilient fender to nearly 1.0 for a flexible fender. For larger ships on energy-absorbing fender systems, little or no deformation of the ship takes place; therefore, a coefficient of 1.0 is recommended.

d) Configuration Coefficient (C_c). This factor has been introduced to take into account the difference between an open pier or wharf and a solid pier or wharf. In the first case, the movements of the water surrounding the berthing ship are not (or hardly) affected by the berth. In the second case, the water between the berthing ship and the structure is squeezed, which introduces a cushion effect that represents an extra force on the ship away from the berth and reduces the energy to be absorbed by the fender system. Therefore, a reduction factor has to take care of this effect. Experience has indicated that for a solid quaywall about one quarter of the energy of the berthing ship is absorbed by the water cushion; therefore, the following values for C_c appear to be justified:

For open berth and corners of solid piers, $C_c = 1.0$.

For solid piers with parallel approach, $C_c = 0.8$.

For berths with different conditions, C_c might be chosen somewhere between these values.

e) Effective Mass or Virtual Mass Coefficient (C_m). When a ship approaches a dock, the berthing impact is induced not only by the mass of the moving ship, but also by the water mass moving along with the ship. The latter is generally called the "hydrodynamic" or "added" mass. In determining the kinetic energy of a berthing ship, the effective or virtual mass (a sum of ship mass and hydrodynamic mass) should be used. The hydrodynamic mass does not necessarily vary with the mass of the ship, but is closely related to the projected area of the ship at right angles to the direction of motion. Other factors, such as the form of ship, water depth, berthing velocity, and acceleration and deceleration of the ship, will have some effect on the hydrodynamic mass. Taking into account both model and prototype experiments, the effective or virtual mass coefficient can be estimated as

EQUATION: $$C_m = 1 + 2D/B \qquad (6)$$

where

D = Maximum draft of ship

B = Beam width of ship

~~The value of C_m for use in design should be a minimum of 1.5 and need not exceed 2.0.~~Formulas for computing the added mass coefficient, such as Equation(6) from PIANC, predict a narrow range of values for C_m, 1.5 for a draft- to- depth ratio of 2.0 and 1.8 for draft- to- depth ratio of 1.1. PIANC recognizes that some investigators have obtained larger values for added mass coefficients but suggests that these results from small scale tests do not accurately model full scale conditions.

The Naval Facilities Engineering Service Center (NFESC) has developed an analytical model which can accurately predict ship berthing impact forces. The model employs a computational fluid mechanics approach, coupling a Reynolds-Averaged Navier-Stokes (RANS) numerical method with a six-degree-of-freedom motion program for time-domain simulation of ship and fender reactions. The model has been verified with data from small scale and full scale tests. Results from the new model for two ship classes yield added mass coefficients close to those calculated by the PIANC formula as long as the depth-to-draft ratio exceeds 1.2. When the underhull clearance becomes small, i.e. for depth-to-draft ratios less than 1.2, predicted added mass coefficients can exceed the PIANC values. Added mass values of 5.0 or higher are predicted for ships berthing against open piers (pile supported) equipped with soft fenders, such as pneumatic or foam-filled cushions. Designers should consider using higher values for the added mass coefficient under these conditions.

f) Berthing Coefficient (C_b). Eccentricity (C_e), geometric (C_g), deformation (C_d), and configuration (C_c) coefficients are sometimes combined into a single value called berthing coefficient.

g) Berthing or Approach Velocity (v). It should be noted that the kinetic energy of the berthing ship is a function of the square of the normal component of its approach velocity. Thus, the kinetic energy as well as the resultant force on the berthing structure are sensitive to changes in approach velocity. By doubling the design value of the approach velocity, the ship's kinetic energy is quadrupled. Design values used for the approach velocity normal to the berth may vary from 0.25 to 1.50 fps, depending on the size of the ship being docked and the tug assistance that is employed. Larger vessels with adequate tugboat assistance can generally berth gently and the lower design velocity may be used. Smaller vessels that self-dock may approach the wharf at considerably higher speeds and, accordingly, the higher design velocity should be used. The berthing velocity is also affected by the difficulty of the approach, maneuvering space for tugs (slip width), and location of the pier or wharf facility. Higher approach velocities should be anticipated when the berth is located in exposed waters where environmental loads cause difficulty in controlling the ship. Also, currents in tidal estuaries in protected waters can be of major concern. Approach velocity normal to the berth may be taken from Figures 44 and 45.

The determination as to whether a facility is "exposed," "moderate," or "sheltered" depends on the environmental conditions at the site and is a matter for professional judgment by the designer. Most naval facilities in the United States are situated in protected waters and can be taken as "sheltered." Where high currents (0.3 fps or more) or strong winds (40 knots or more) occur frequently, a "moderate" condition should be assumed. The "exposed" condition may be used when unusually severe currents and winds are present. However, local experience with ship berthing should control the selection.

5.2.3 Example Calculation. Compute the energy to be absorbed by a fender system in a tug-assisted berthing of a vessel at a pier located in a sheltered basin. The following information is furnished:

Water depth at berth .... 35 ft

Berthing draft, fully loaded .... 28 ft

Displacement, fully loaded ....20,500 long tons

Length .... 564 ft

Beam . . . . 81 ft

$C_b = C_e \times C_g \times C_d \times C_c .= 0.5$

$E_{fender} = ½\, Wv^2/g \times C_b \times C_m$

v from Figure 45 = 0.27 fps

$C_m = 1 + 2B/D = 1 + 2(28/81) = 1.69$

$E_{fender} = ½ \times (20{,}500/32.2) \times (2250/1000) \times 0.272 \times 0.5 \times 1.69$

= 44.1 ft-kips

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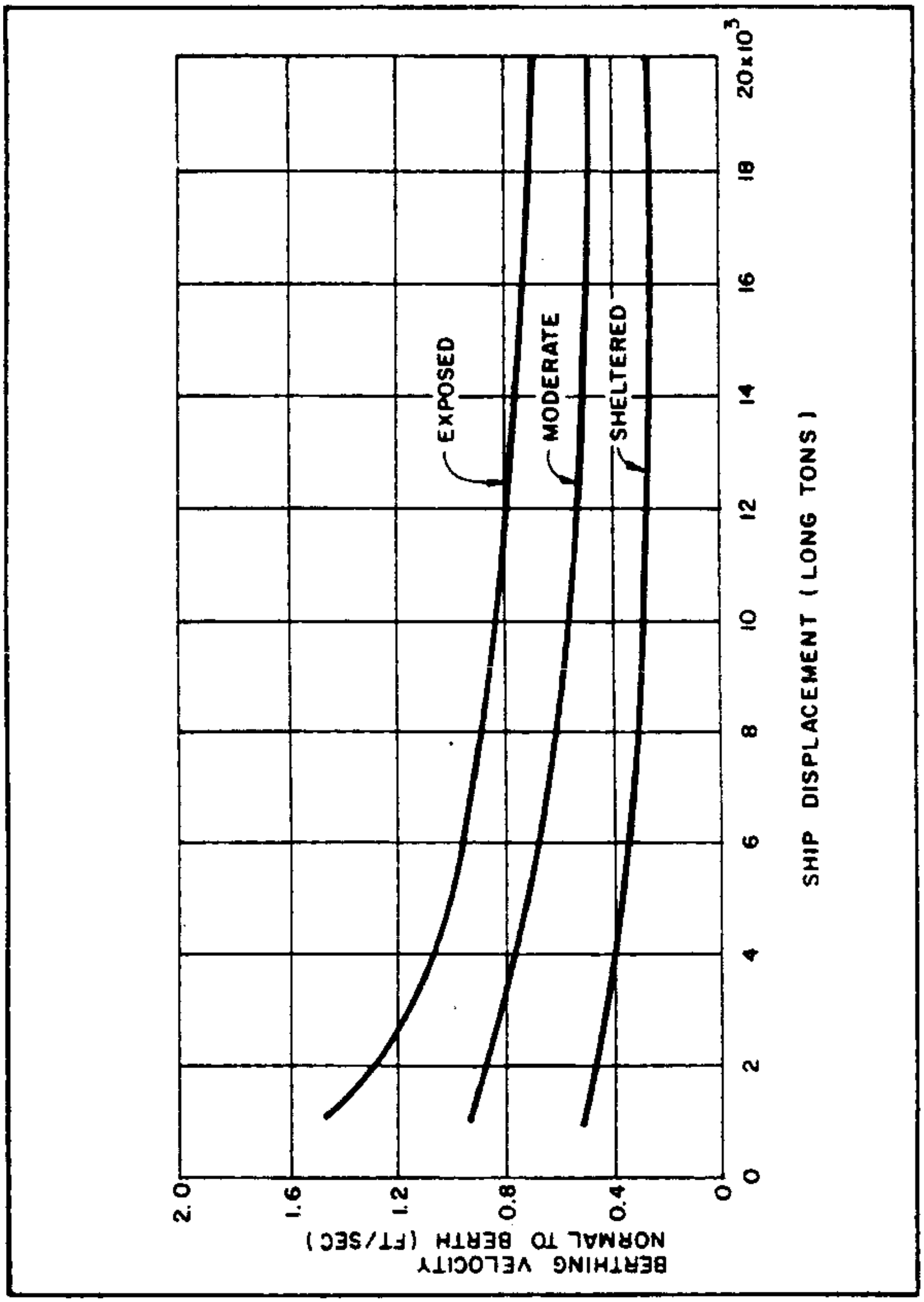

Figure 44
Berthing Velocity for Small Ships (up to 20,000 tons)

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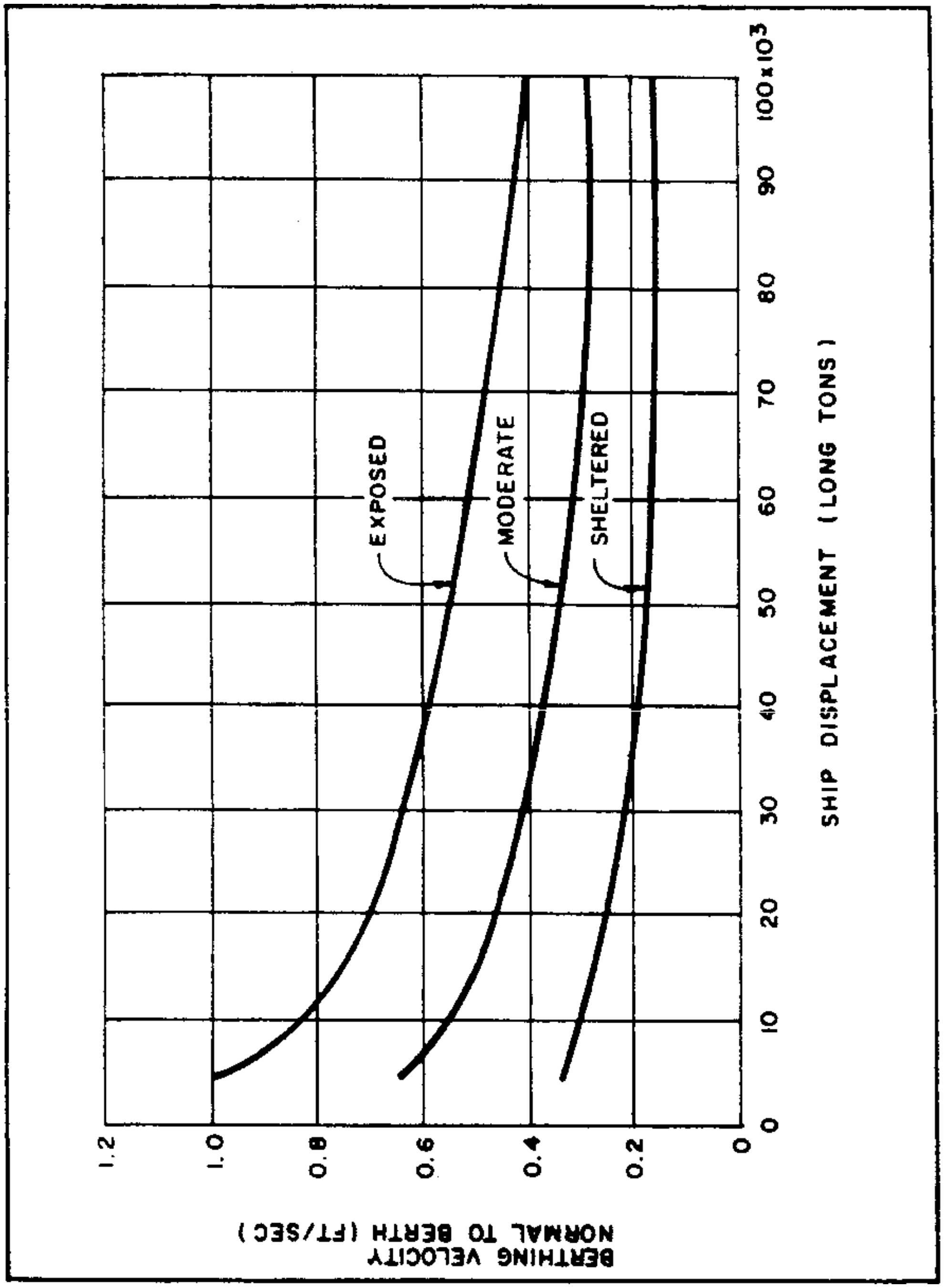

Figure 45
Berthing Velocity for Large Ships

5.2.4 Berthing Energy for Submarines. The kinetic method for calculating berthing energy as explained above is generally applicable for submarines. However, the formula for computing the effective mass coefficient (C_m) is not applicable. The cognizant naval agency, such as NAVSEA, should be contacted for a recommendation for C_m based on the model study for the specific class of submarine. Because submarines will always be tug-assisted and berthed against camels, the approach velocity as obtained from Figure 44 for sheltered-to-moderate conditions may be used in the absence of more specific information.

5.3 Types of Fender Systems.

5.3.1 General. Fender systems absorb or dissipate the kinetic energy of the berthing ship by converting it into potential energy in the fender materials. This could be in the form of deflection of a fender pile, compression of a column of rubber, deformation of a foam-filled cylinder, torsion of a steel shaft, or pressuring of a pneumatic fender. Other energy conversion processes are possible. Hydraulic fenders absorb energy in the form of heat. However, most practical systems use the potential energy conversion and are the only systems to be considered.

5.3.2 Fender System Components.

5.3.2.1 Fender Piles. ~~Although timber and steel piles are the most commonly used, prestressed concrete is also being studied as a possible fender pile material. The fender piles usually are connected to a chock and waler system at the deck level and supported by rubber fender units to the bullrail. In the working stress range, there is a linear relationship between reaction force and deflection.~~Although timber, steel and prestressed concrete piles are the most commonly used, composite piles are also being introduced. There are two primary types of composite piles. One is made of fiber reinforced plastic (FRP) in the form of a tube which can be filled with concrete for greater strength and stiffness. The second is made of thermoplastics (such as high-density polyethylene, HDPE) and reinforced with either steel or FRP strands. These types of composite piles have been in use at several Naval bases with generally favorable results. The fender piles are usually connected to a chock and waler system at the deck level. Rubber fender units are sometimes placed between the wale and pier deck fascia for additional energy absorption capacity. In the working stress range, there is an approximate linear relationship between reaction force and deflection. Because of a higher susceptibility to abrasion and impact damage the thermoset FRP tube type pile should have rubberized abrasion strips installed at potential contact points with berthed vessels.

The reinforced thermoplastic type pile generally exhibit larger load-deflection properties compared to conventional wood, steel or concrete piles. To ensure uniform loading and avoid premature failure of fender system components these type piles should not be used in parallel or mixed with conventional type piles in the same system.

5.3.2.2 End-Loaded Rubber Fenders. These work by elastic compression of hollow rubber cylinder elements with small length-to-diameter ratios. As shown in Figure 46(A), steel fender panels with special rubbing material facing are usually required to minimize wear. The reaction force is an exponential function of the deflection. These fenders are usually attached directly to the pier or wharf structure in the form of a "cell fender."

5.3.2.3 Side-Loaded Rubber Fenders. These are hollow rubber units available in trapezoidal, circular, square, or D-shapes that, when loaded at their side, deform by trying to flatten out. See Figure 46(B). The potential energy is stored by a combination of compression and bending of the rubber elements. The reaction force is an exponential function of the deflection and the performance curve is quite similar for all the shapes. Fenders having a curved rather than flat external surface increase in stiffness more gradually as the area of contact increases during deformation. All these fenders experience a sharp and rapid increase in stiffness when the amount of deflection completely collapses the open bore, regardless of their external contour. Side-loaded rubber fenders will not absorb large amounts of energy and are not generally used alone. They are usually provided at the top of fender piles in discontinuous pieces, as shown in Figure 54.

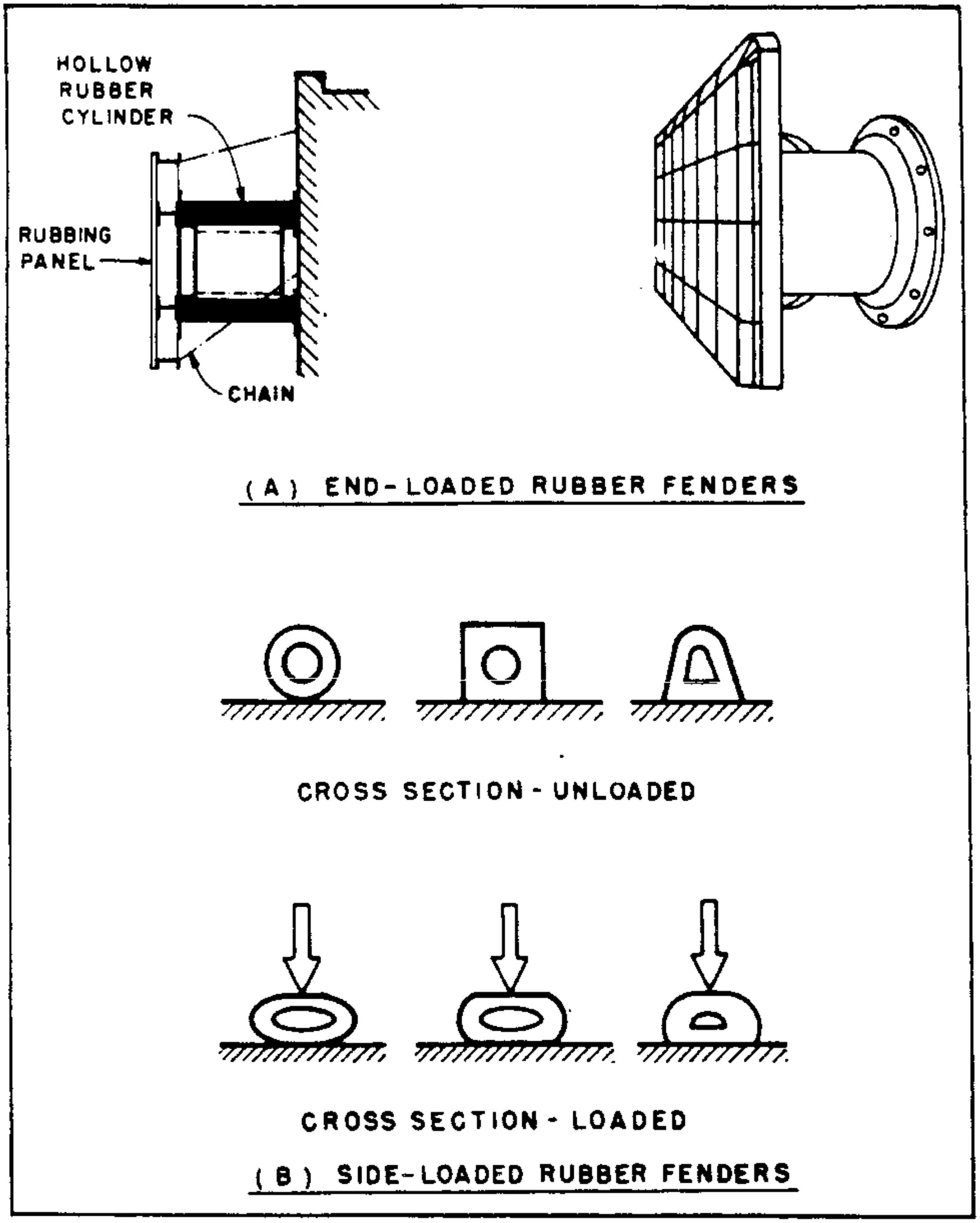

Figure 46
Side-Loaded and End-Loaded Rubber Fenders

5.3.2.4 Rubber Shear Fenders. The potential energy in these units is stored as elastic shear deformation of the rubber. Usually, a solid rubber block is vulcanized between two metal plates and the force is transferred through a fender frame or panel, as shown in Figure 47. These fenders are highly sensitive to proper manufacturing and installation as they depend on the bond between steel plates and the rubber. The force-deflection relationship is essentially linear.

5.3.2.5 Buckling Fenders. These fenders operate on the buckling column principle in which a molded column of rubber is loaded axially until it buckles laterally. The end-loaded cylinder fenders described earlier are actually a buckling fender in principle. Most buckling fenders are not well suited for direct contact with a moving ship and hence are used with an abrasion or protector panel, as shown in Figure 48. The reaction force is linear up to a level when the pure compression behavior changes to the buckling mode. Hence, initially a relatively high reaction is built up with a small deflection, which then stays constant through the rest of the deflection range. ~~Since~~Because buckling fenders are intended to buckle in a predetermined direction, any lateral deflection can significantly reduce their effectiveness. When lateral loads in either direction (parallel to length of berth or up/down) are anticipated, a cell-type fender is preferred. These fenders are becoming increasingly popular for berthing very large ships as they can absorb very high energy with a constant reaction force.

5.3.2.6 Pneumatic **/ Hydro-Pneumatic** Fenders. The potential energy in these fenders is stored by the elastic compression of a confined volume of air. By varying the internal pressure of air, the energy-absorption characteristic can be changed. To prevent the air pressure from increasing to a "blowout" level, pneumatic fenders are provided with a relief valve or deflection limiter within the body of the unit. The shell construction for these fenders is similar to an automobile tire with several laminations to provide the high tensile strength required. The surface pressure of these fenders is uniform, resulting in uniform hull pressure. Reaction force is an exponential function of deflection. The basic types of pneumatic fenders in common use are discussed below:

a) Air Block and Air Cushion. The shells for these are chemically bonded and mechanically coupled to a rigid mounting plate that can be attached to a solid face of the berthing structure. See Figures 49(C) and 49(D).

b) Floating. The floating type is usually cylindrical in shape with hemispherical ends and is attached to the structure by chains. It floats on the water and rises and falls with the tide. The unit requires a backing system to distribute the load. As shown in Figures 49(A) and 49(E), large floating pneumatic types are covered with a net of used automobile tires and cylindrical rubber sleeves to protect the fender from puncture and abrasion. The tire net and chains also form the means for rigging and attaching the fender to the pier.

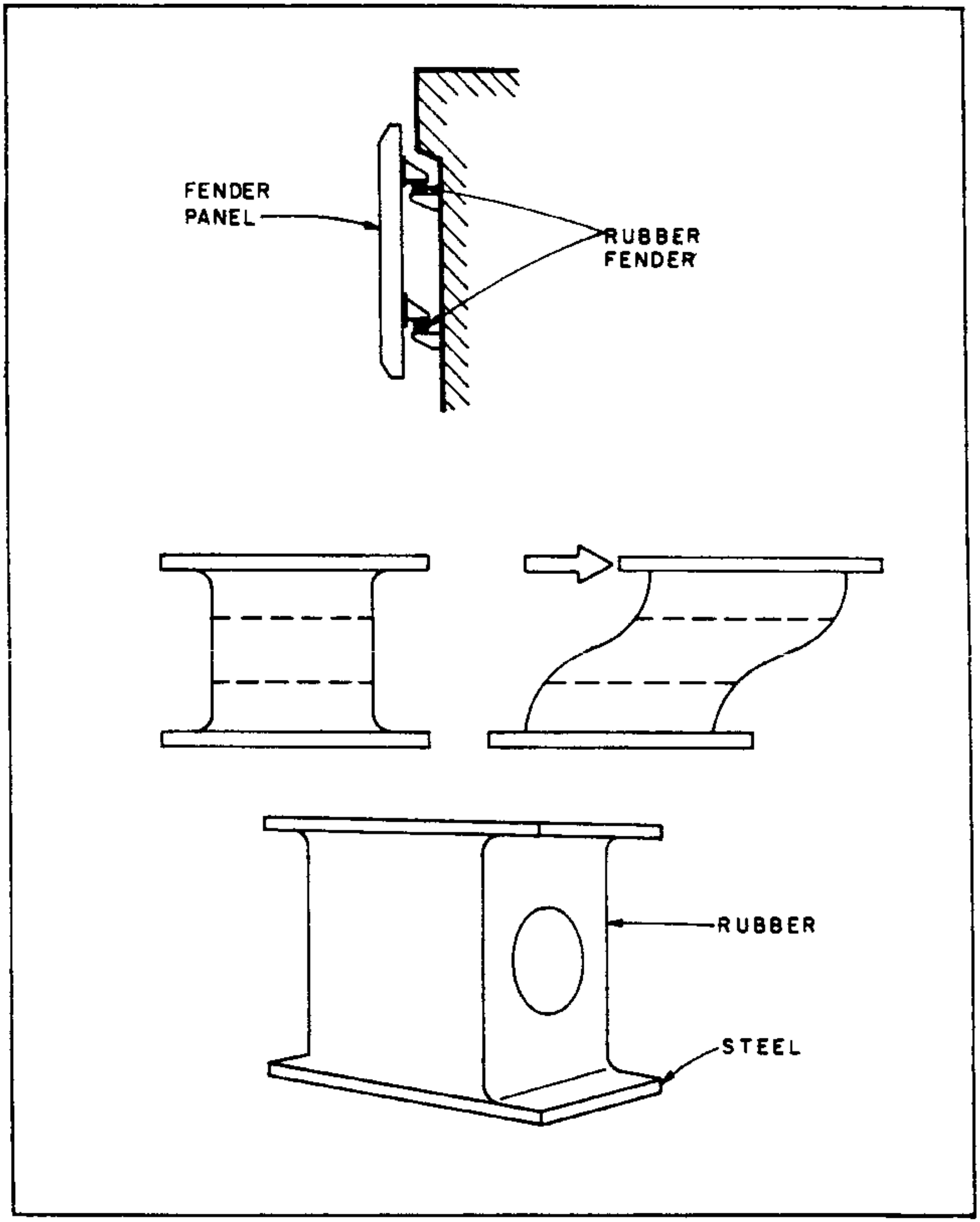

Figure 47
Shear Fender

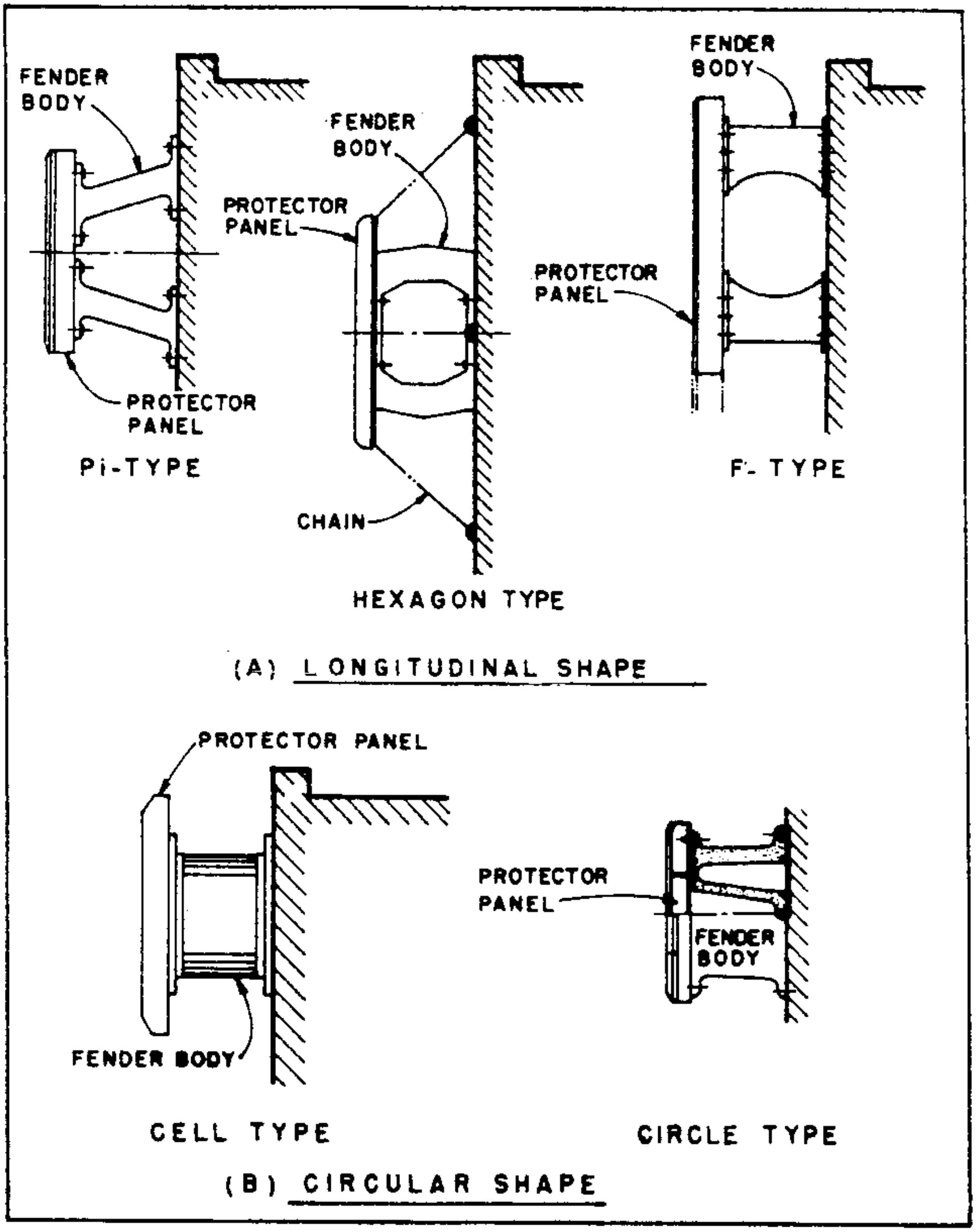

Figure 48
Buckling Fender with Contact Panel

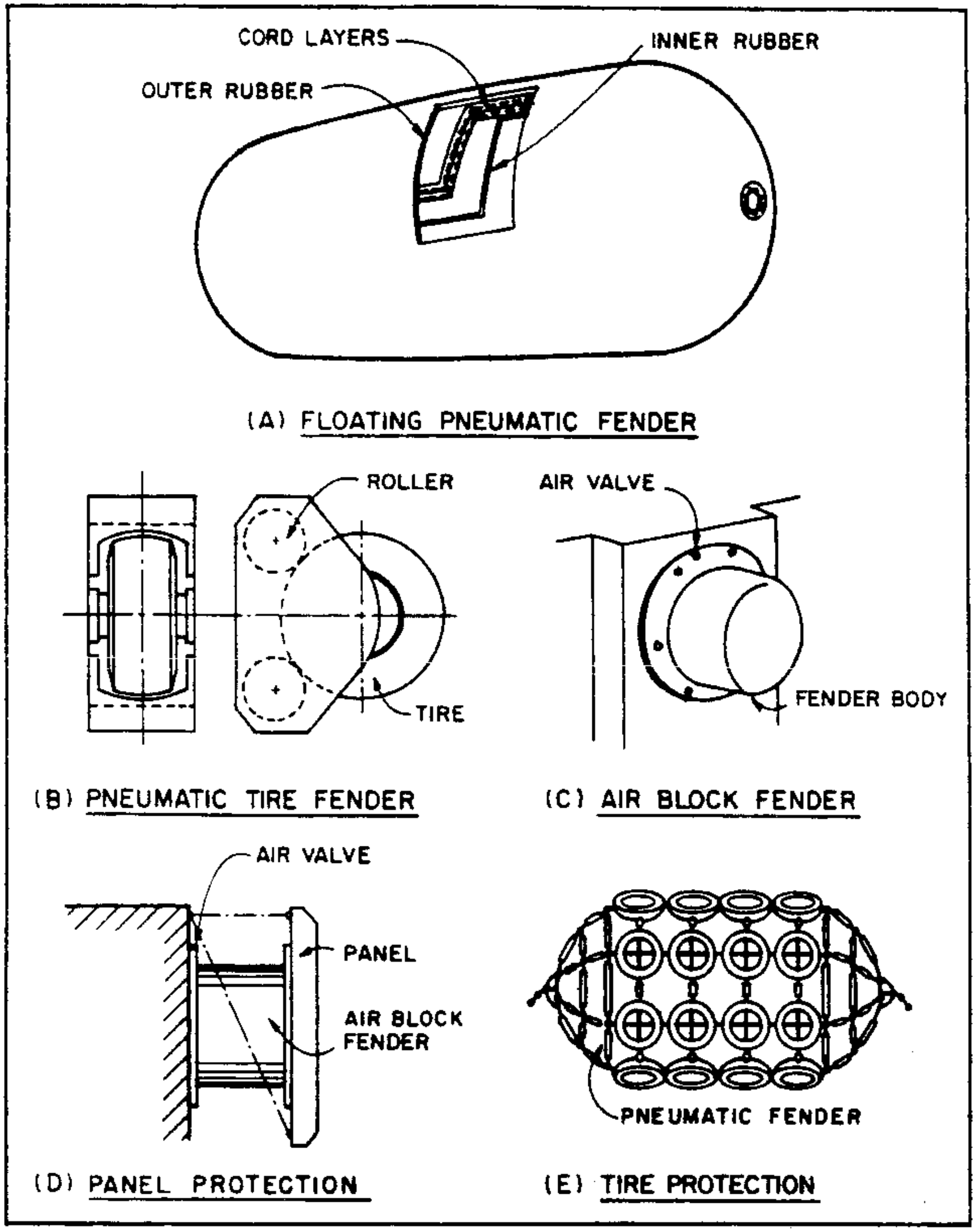

Figure 49
Pneumatic Fenders

c) Tir~~l~~e. This type consists of a large-diameter tire mounted on an axle and backed by rollers. The unit can be mounted with its axis of rotation vertical or horizontal. This type is particularly suited for pronounced corners of the structure where ships may have approach difficulties. See Figure 49(B).

d) Hydro-Pneumatic. This type of fender has been developed for use with submarines and consists of a vertically mounted cylindrical pneumatic fender partially filled with water and backed by a closely spaced group of fender piles. See Figure _??? {USE FIGURE FROM DUANE DAVIS 3/30/99 REPORT}. A ballast weight is added to adjust the degree of submergence of the fender to coordinate the vertical center of the fender with the horizontal center of the submarine hull. The fender unit floats with the tide and therefor stays in the same relative position with the vessel.

5.3.2.7 Foam-Filled Fenders. These are constructed of resilient, closed-cell foam surrounded by an elastomeric skin. Additional protection against abrasion can be provided by thicker elastomeric coatings or an external tire net, similar to the floating pneumatic type. The fender requires a backing system to distribute the load. Netless fenders cost more due to the need for thicker skins and coatings. However, the greater hull marking of the tire net and occasional maintenance need suggest that netless fenders may be preferred. The unit floats up and down with the tide and is held in place with chains. The cellular structure of the foam filling reacts like hundreds of millions of individual pneumatic fenders in deforming and absorbing the energy. The foam contains the air within its cellular structure and tends to compress upon itself rather than bulge peripherally. The foam-filled fenders have a high energy absorption with comparatively small reaction force. Surface pressure of the fender is not quite uniform when it is compressed, so the hull pressure over the contact area is not quite uniform. Where rough concrete surfaces of the backing surface or pretressed concrete piles is a concern, consideration should be given to using UHMW pads or strips to protect the skin of the foam filled fender ***{should this be required?}.*** See Figure 50 for construction and installation details.

5.3.3 Fender Systems. The components discussed above, used individually or in combination along with the ship, separator, and structure, form the fender system. Usually, very little energy is absorbed in the form of ship deformation. Separators also have little or no energy-absorption capability by themselves, unless a fender unit is installed between the ship and the separator. The structure in most cases is assumed to be inflexible and energy absorbed is not counted. However, in berthing against breasting dolphins in deep waters, the energy absorbed by the structure is significant and may be taken into account. The following are the commonly used fender systems.

5.3.3.1 Fender Piles with Side-Loaded Rubber Units. This is the most commonly used system in existing Navy piers and wharves. This system is stiff and lacks deflection which results in high reaction loads and frequent breakage of piling and hull damage. As shown in Figure 51, this system employs a series of closely spaced fender piles (5- to 10-ft spacing) connected together by chocks and walers. A rubber fender unit is mounted between the waler and the berthing structure. A series of diagonal chains from the structure to the waler completes the system. The system has ~~worked very well~~ been widely used in both naval and commercial facilities~~ when used with~~ ~~t~~Tight-fitting joints between chocks, walers, and pile head, ~~and when~~ with proper tension splices that provide compression and tension continuity along the face of berth~~ are used~~must be provided. See NFESC SP????, “Design Criterial for Chocks and Wales” for guidance on the design of chocks and wales. Ships may be berthed either directly or through a log camel. However, when camels are used, the fender piling must be sized to resist the resulting bending. Although timber piles are more common, steel piles have also been used. Concrete piles appear to have significant advantages over steel and timber in this type of application. The concrete piles may also be designed to allow large deflections and energy absorption and are being tested by the Navy. See ~~Naval Civil Engineering Laboratory (NCEL)~~ NFESC TM 51-85-19, Development of Prestressed Concrete Fender Piles Preliminary Tests and NFESC TM 53-89-03, Prestressed Concrete Fender Piling User Data Package. For specification guidance see NFGS 02395, Prestressed Concrete Fender Piling.

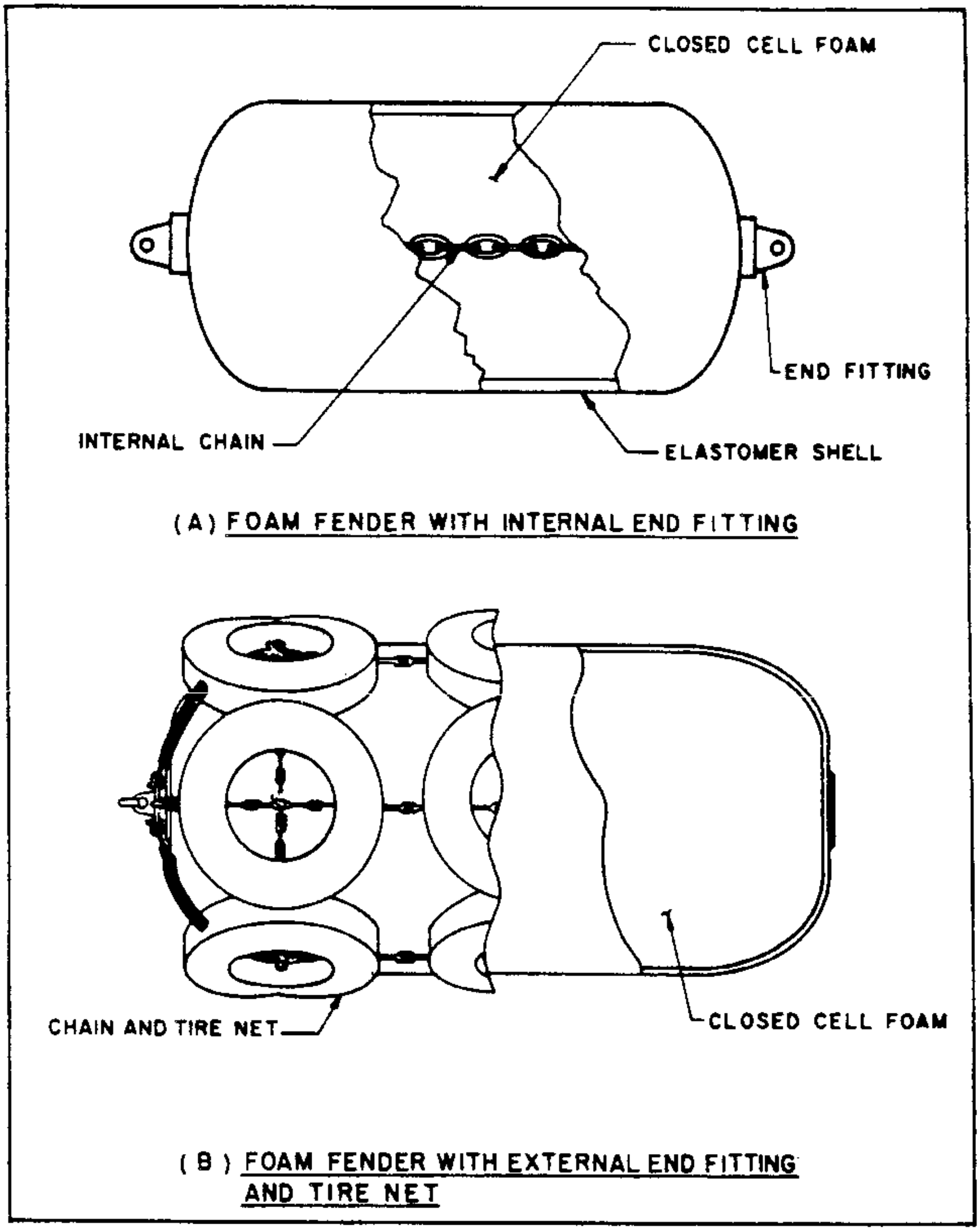

Figure 50
Foam-Filled Fenders

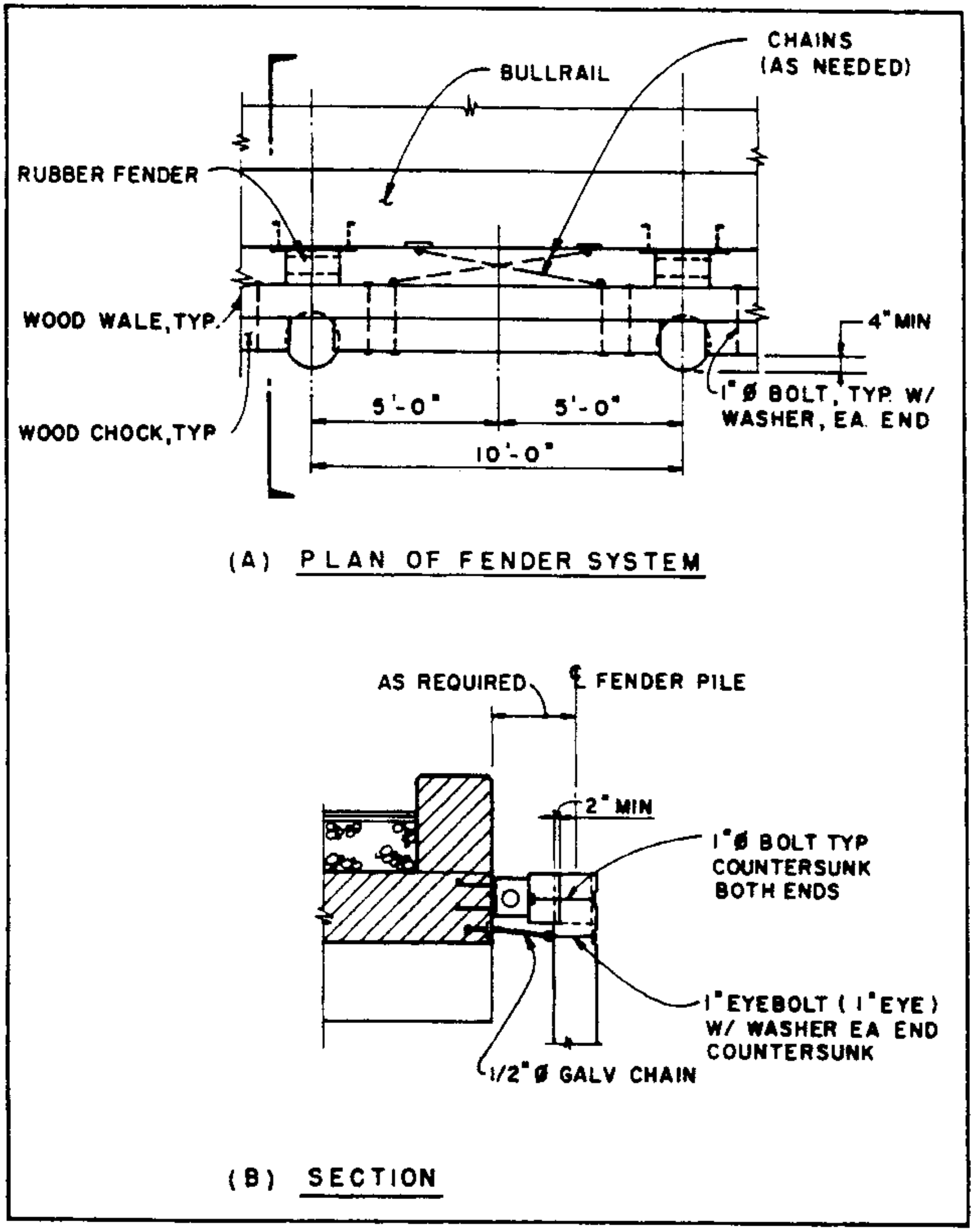

Figure 51
Fender Pile with Side-Loaded Fenders

?UPDATE WITH SKETCHES FROM NFESC REPORT ON CHOCKS & WALES?

The system provides good berthing flexibility. Ships of different sizes, tugboats, submarines, and barges can be accommodated without any modification. However, when used with floating camels, which tend to cock between the ship and the piles, the ship's energy may become concentrated on just one or two piles. Hence, unless the floating camel is tightly secured to the piles (guided by piles), the system will not work well and frequent damage will occur. The pile-rubber system is not recommended for solid and other types of piers and wharves where full deflection of the piles within the working range will be ~~ prevented~~inhibited. When this system is employed throughout the length of berth, the rubber fender units should be sized for direct berthing of ships (without the use of camels).

5.3.3.2 Directly Mounted Fender Units. In this system, individual fender units like the cell or buckling column type are attached directly to the pier or wharf face. For narrow tidal range in solid piers and wharves, and for narrow vessel size range, this system may be cost-effective for direct berthing of surface ships. However, additional fender types will have to be used for berthing submarines and for berthing ships with a separator. Although this system is very popular in commercial piers and wharves throughout the world, it may not be suitable for some naval facilities. **This system is subject to damage from snagging on ship protrusions at levels of 8 to 10 feet above the water line and from vertical loads resulting from snags on rails and protrusions during falling tides** or from lateral loads due to snags on protrusion during longitudinal movement of the ship.

5.3.3.3 Floating Fender Units. This system consists of foam-filled or pneumatic fender units and a backing system. As the fender units can be positioned to float with the tide, several surface ship types can be handled. The backing system should be designed to work with the fender unit for the full tidal range. ~~Since~~Because the floating units are usually rather large, they provide a good standoff and may function as a separator as well. The berthing structure may be designed with the backing system at different points along the length of berth and the fender units moved around as berthing plans change. Some promising backing concepts are shown in Figures 52 and 53. When clustered piles or sheet piles are used for the backing system, additional energy can be absorbed by the piles and their support systems at the deck level.

5.3.3.4 Combination System. Any of the above-mentioned fender systems may be combined in the same berth to make up the deficiency of another. A berth may have either the floating fender units or directly mounted fenders at discrete points, with the in-between spaces filled up by the pile/rubber system designed to work with separators. Floating fenders and directly mounted fenders may be used alternately along solid or two-story types of piers and wharves. Combination systems are illustrated in Figure 54.

5.3.3.5 Monopile System. This ~~is a proprietary~~ fendering system is based on the use of a floating ring-shaped resilient fender unit which rides up and down on a large steel pile driven to the seabed. Special low-friction bearing pads are usually installed on the inner surface of the hull of the ring fender so that the fender unit can rotate and slide freely on the pile. This unique ability makes the monopile system very suitable for corner protection of piers and wharves and entrances to a narrow slip. The units can also work well as breasting and turning dolphins. Energy is absorbed both by the steel monopile in flexure and by the ring-shaped fender unit. This system is illustrated in Figure 55.

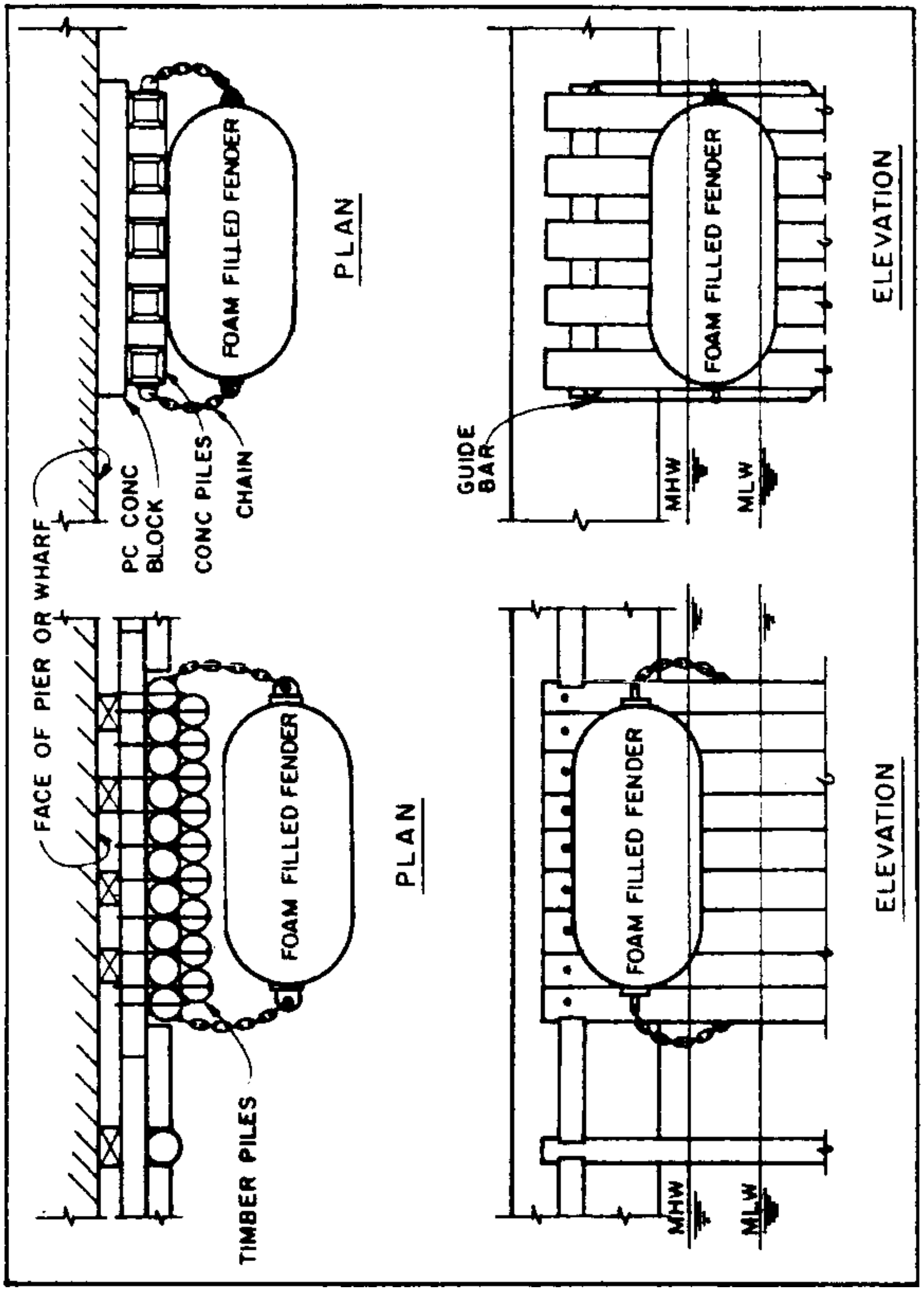

Figure 52
Cluster Pile Backing for Foam-Filled Fenders

ADD NOTE SHOWING UHMW POLYETHELENE PADS BETWEEN FFF & P/S CONCRETE PILE??

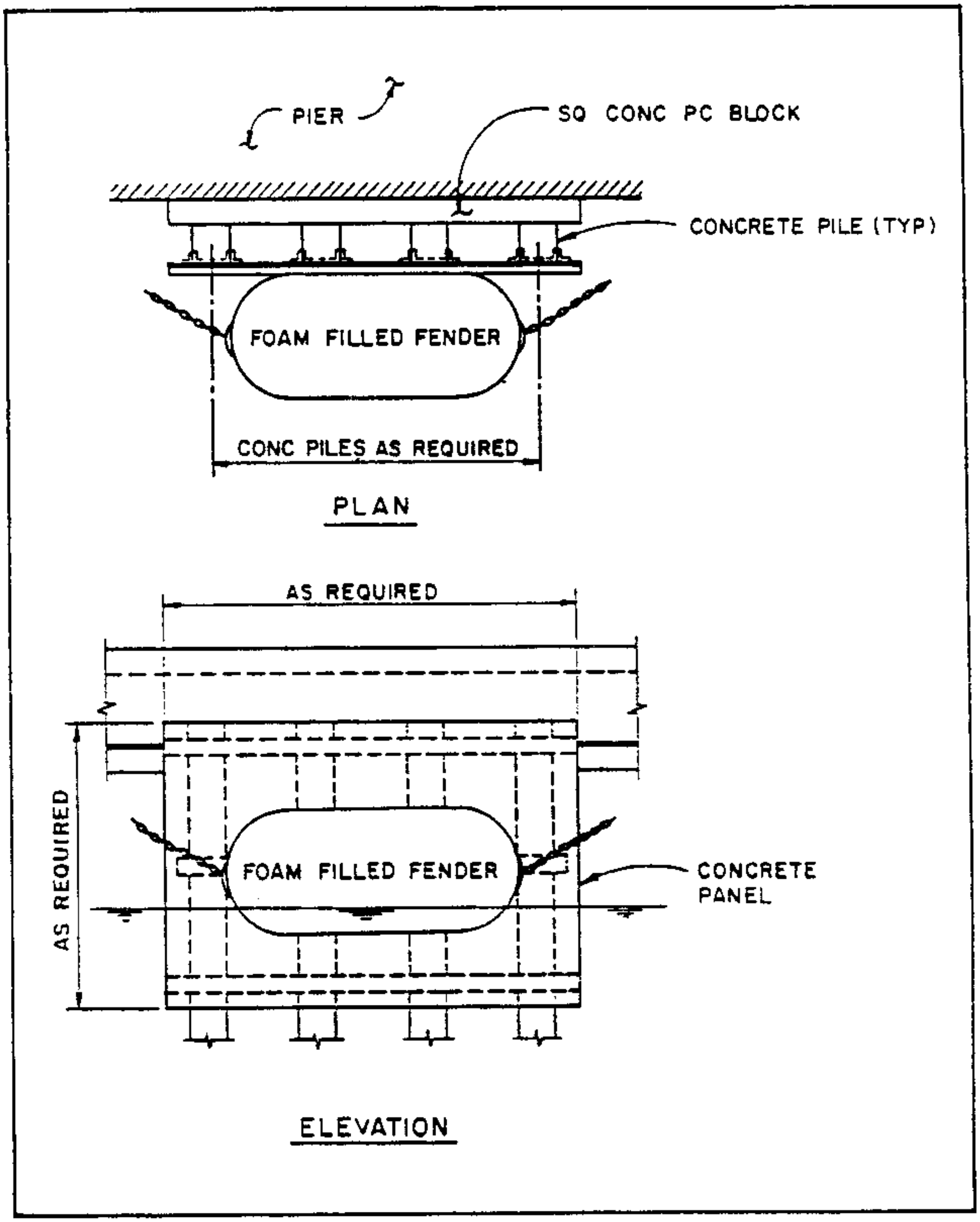

Figure 53
Concrete Panel Backing for Foam-Filled Fenders

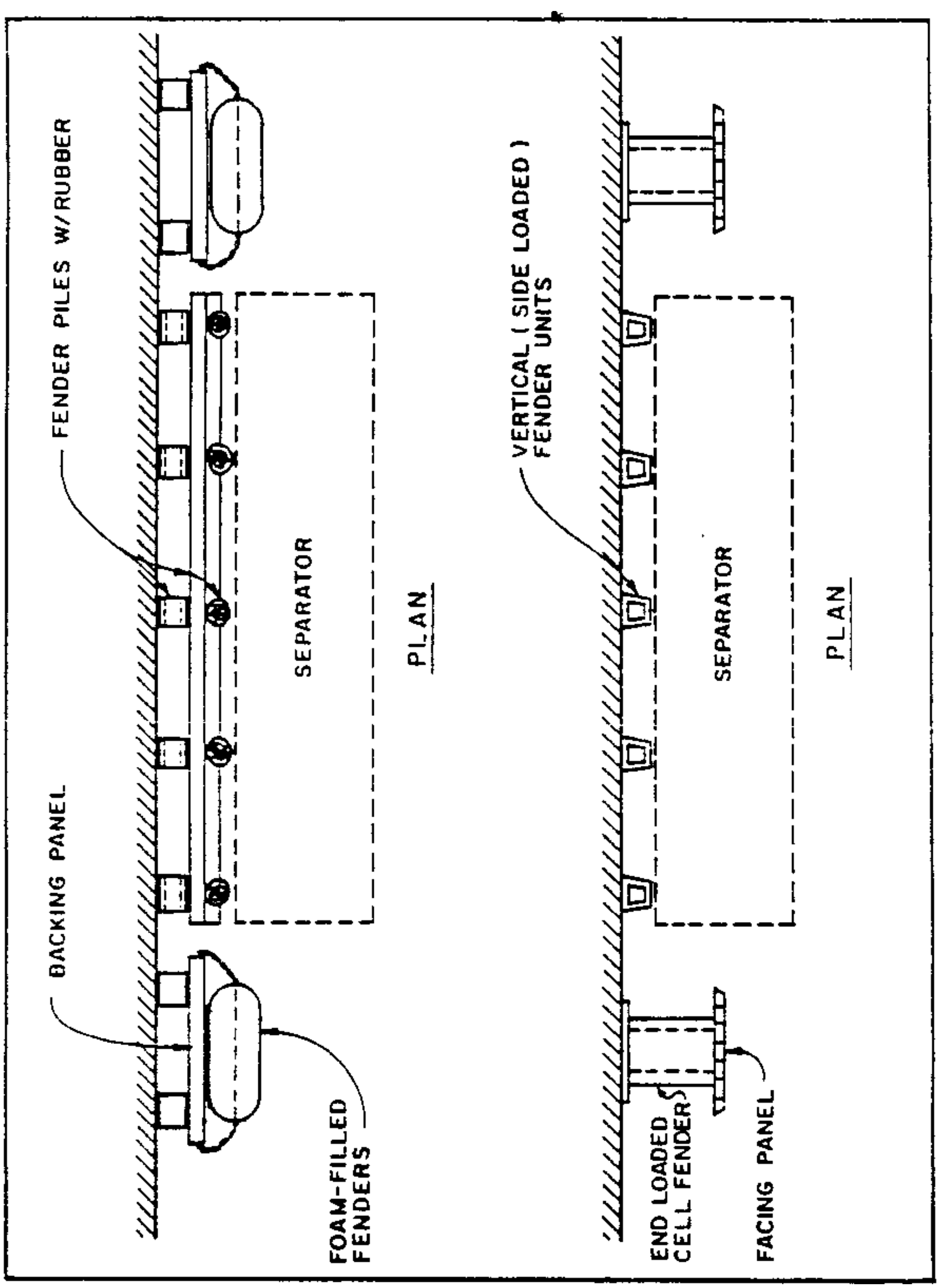

Figure 54
Combination Systems

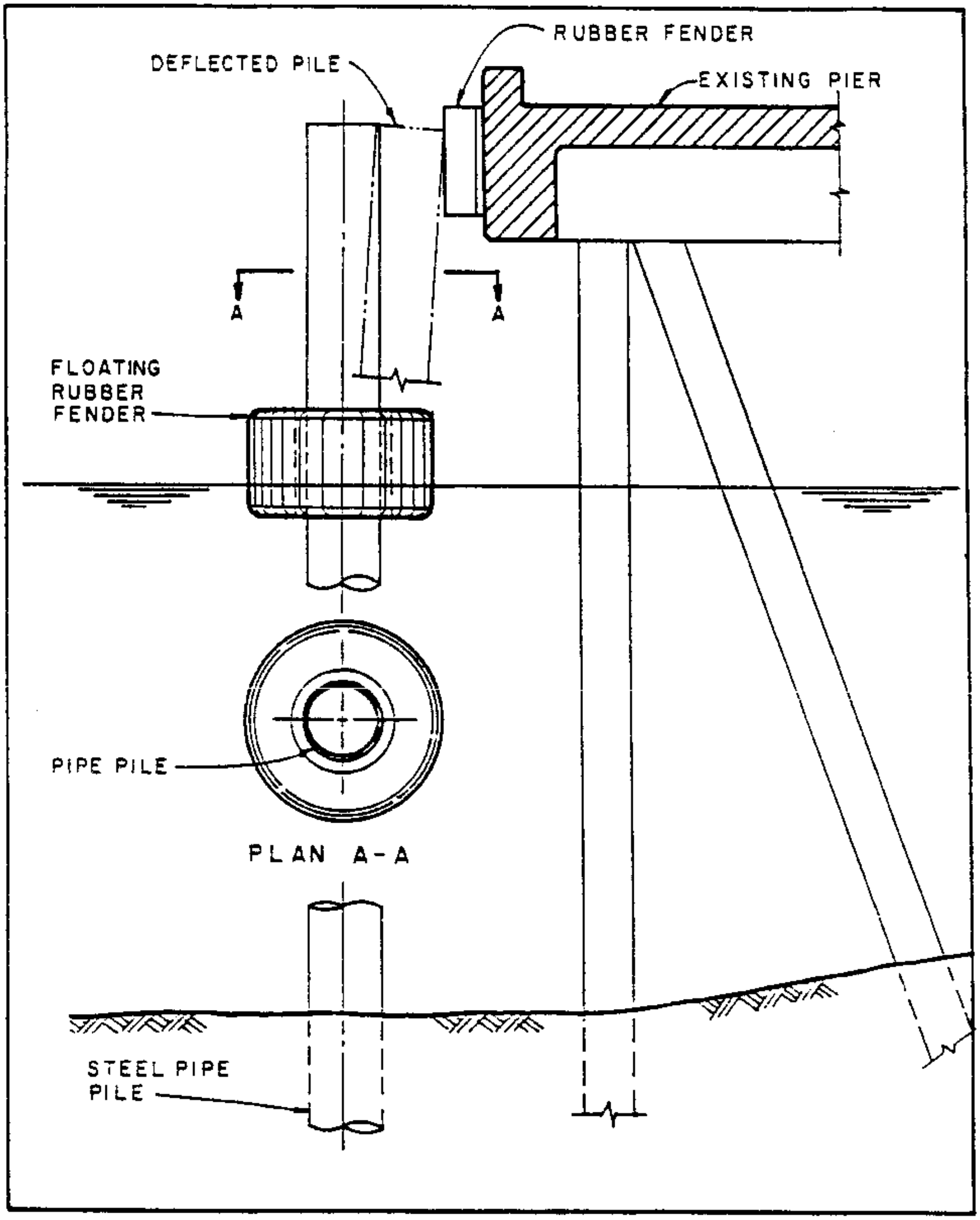

Figure 55
Monopile Fender System

5.4 Selection and Design of Fender Systems.

5.4.1 General. The major factors which influence the selection of the best fender system for a particular situation include the following:

a) Energy-Absorption Requirements. The fender system must have sufficient energy-absorption capacity to absorb the kinetic energy of the berthing vessel.

b) Reaction Force. This is the force which is exerted on the ship's hull and on the berthing structure during impact. The reaction force has a significant effect on the design of the berthing structure.

c) Hull Pressure. This is the pressure exerted on the ship's hull by the fender unit and is derived by dividing the reaction force by the fender area in contact with the ship. Hull pressure must be limited to levels which will not cause permanent damage to the berthing ship.

d) Deflection. This is the distance, perpendicular to the line of the berth, that the face of the fender system moves in absorbing the ship's kinetic energy. The magnitude of the deflection allowable will be controlled by other protrusions from the berthing face and the ship.

e) Reaction/Deflection Relationship. The nature of the reaction deflection relationship determines the relative stiffness of the fender system.

f) Long-Term Contact. This includes the changes in environmental conditions (i.e., wind, current, waves, and tide) during loading and unloading at the berth. The fender system should not "roll up," tear, abrade, or be susceptible to other forms of damage when subject to long-term contact.

g) Coefficient of Friction between the Face of the Fender System and the Ship's Hull. This determines the resultant shear force when the ship is berthing with longitudinal and/or rolling motion and may have a significant detrimental effect on the energy-absorption performance of the fender system. The magnitude of the shear force also may have a significant effect on the cost of the berthing structure.

h) Degree of Exposures. Where the berth is exposed to severe wind, current, and/or wave action, the fender selection may be governed by the design mooring conditions rather than berthing conditions.

i) Life-Cycle Costs. Capital costs for both the fender system and the structure, as well as operation, maintenance, and repair costs, must be evaluated.

j) Berthing Practice. The capability of the crews responsible for berthing the ship will have an effect on the energy-absorption requirement of the fender system. The berthing velocity and angle of attach are affected by the local berthing practice.

k) Maintenance. Where maintenance is expected to be infrequent, a simple, possibly less efficient, fender system may be preferable to a system requiring a higher degree of maintenance.

l) Local Experience. Fender types already used locally should be considered ~~since~~because their performance under actual conditions is known. Also, there may be an advantage in having interchangeability of spares, particularly if the number of new fenders required is small.

m) Frequency of Berthing Operations. A high frequency of berthings normally justifies greater capital expenditures for the fender system.

n) Range of Ship Sizes Expected to Use the Berth. While the energy-absorption capacity of the fender system may be selected for the largest ship expected to use the berth, the fender system must be suitable for the full range of ships that the berth will accommodate. The effect of hull pressure and fender stiffness on the smaller vessels may have a significant influence on the selection and arrangement of the fenders.

o) Shape of Ship's Hull in Contact with the Fender System. Where vessels with unusual hull configurations or protrusions may be expected to use the berth or where the berth must accommodate barges, special attention must be paid to the selection and arrangement of the fender system.

p) Range of Water Level to be Accommodated. The fender system must be suitable during the full range of water levels that may occur at the berth. The design must consider both the largest and smallest vessels, in both the loaded and light conditions, at high and low water levels. Where extreme water level variations occur, consideration should be given to the use of floating fender systems.

q) Separators. The size, type, and number of camels used in berthing operations will seriously influence selection of the fender system.

5.4.2 Fender System Behavior. The fender systems having the most promise for new installations can be classified into three groups in terms of their behavior:

(a) The flexible pile types similar to those shown in Figure ?? have basically a linear force-deflection relationship. Cantilevered piles or “monopile" systems likewise have a basically linear force-deflection relationship.

(b) The buckling column types behave linearly up to a point where the rubber starts to buckle and behave nonlinearly from there on.

(c) The pneumatic, foam-filled, and side-loaded rubber fenders exhibit very similar behavior with the reaction force building up more than proportional to increasing deflection. These behaviors are illustrated in Figure 56.

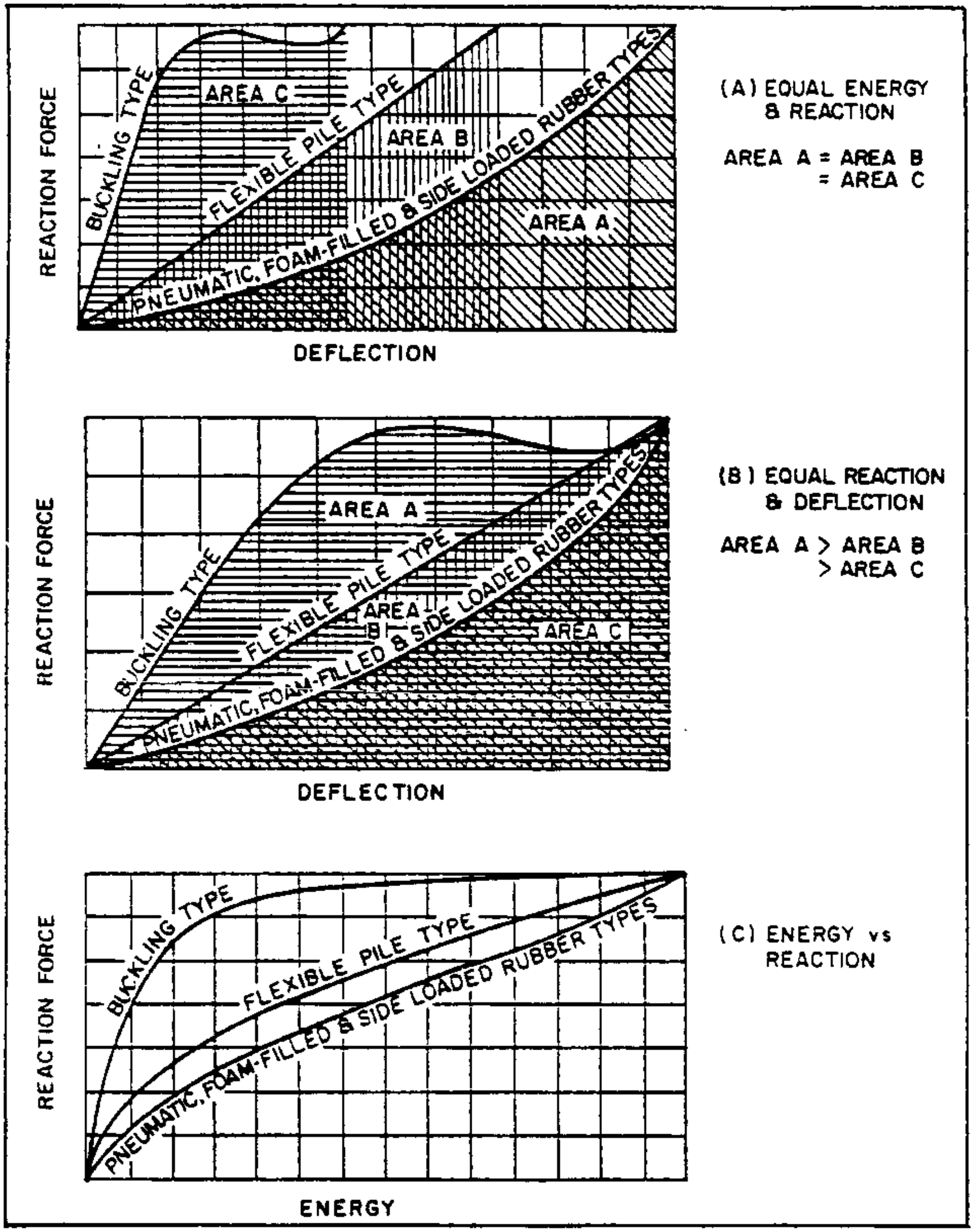

Figure 56
Evaluation of Fender System Types

5.4.3 Evaluation of Alternatives.

5.4.3.1 Equal Energy and Reaction. Figure 56(A) illustrates the reaction-deflection characteristics of the three types of fender systems. The area under each of the reaction/deflection curves represents the energy absorbed by that type of fender. Each of the curves in the figure represents fender systems with equal rated reactions and equal energy-absorption capability. It is evident from the figure that, while the fenders of the various types illustrated provide equal energy absorption at equal rated reactions, the energy-absorption capacity is achieved through different deflections, with the buckling type deflecting the least.

5.4.3.2 Equal Reaction and Deflection. A comparison of the various types of fenders may alternatively be considered on the basis of equal rated reaction and equal deflection, as illustrated in Figure 56(B). This situation often occurs when new fender units are installed in conjunction with, and compatible with, an existing fender system. It may also occur when a replacement fender system is installed in an existing facility with cargo transfer equipment of limited reach. It is evident from the figure that the buckling type fenders have considerably more energy-absorption capacity for the same reaction and deflection than the other types.

5.4.3.3 Reaction versus Energy Absorbed. Comparing the various types of fender systems from the point of view of the reaction force that is developed for a given energy-absorption capacity, as illustrated in Figure 56(C), it is evident that the pneumatic, foam-filled, and side-loaded rubber type fender units are the "softest." They have greater energy-absorption capacity at reaction levels less than their maximum rated reaction. This characteristic makes these fenders particularly attractive at berths which must accommodate a wide range of vessel sizes ~~since~~because the fenders will deflect significantly even when subjected to relatively small berthing impacts.

5.4.3.4 Accidental Overloads. Also to be considered in the selection of a fender system are the consequences of an accidental overload of the system. The buckling and side-loaded rubber fenders "bottom out" if compressed beyond their maximum rated deflection, with resultant high reaction forces and the potential for severe damage to the berthing vessel and the support structure. The reaction of flexible pile fender systems will continue to increase at a uniform rate when overloaded until the yield stress of the pile material is reached, at which point continued deflection will occur as the material yields with no appreciable increase in reaction. Foam-filled fenders, when compressed beyond their maximum rated deflection, will exhibit a steadily increasing reaction and will incur permanent deformation and consequent loss of future energy-absorption capacity. The pneumatic fenders are normally fitted with relief valves so that when overloaded they continue to absorb energy with no increase in reaction beyond that which corresponds to the relief valve setting and no permanent damage to the fender unit.

5.4.3.5 Buckling Fenders. ~~Since~~Because the buckling type fender systems have the highest energy-absorption capacity for a given deflection and reaction, they are in very wide use in commercial piers and wharves. Due to the nature of the reaction/deflection/energy-absorption relationship of these types of fenders, as illustrated in Figure 56(C), a very high reaction (close to maximum) occurs during virtually every berthing operation and the berthing structure must be designed with this fact in mind. This fact also causes the fender to be relatively rigid when smaller ships use a berth designed for larger ones. Many buckling-type fenders cause rather high contact pressures against the ship's hull and consequently require a panel to distribute and thus reduce the pressure. The panel must be sized and located to ensure proper contact with both the largest and smallest vessels to use the berth. Another characteristic of these fenders which must be considered is their lowered performance when impacted by a vessel approaching at an angle to the berth or with a velocity component in the longitudinal direction. The reduction in energy-absorption capacity may be as much as 20 percent when the approach angle is 5 deg. to 10 deg., with additional reduction when combined with shear strain.

5.4.3.6 Floating Fenders. The floating pneumatic and foam-filled fenders have a similar appearance and similar reaction/deflection relationship. Compared to the buckling types, these fenders require greater deflection for a given reaction and energy-absorption capacity. The pneumatic and foam-filled fenders present a very large surface to the ship's hull and consequently have low hull contact pressures. This eliminates the need for a panel between the ship and the fender. With the pneumatic and foam-filled types of fenders, the maximum reactions will normally occur only a very few times during the life of the facility, permitting the use of higher stress levels in the supporting structure. However, they require a rather large, solid face on the supporting structure, which may increase its costs. The main difference between pneumatic and foam-filled fenders is that the former will lose its strength completely when punctured by ship protrusions and that the latter may lose a significant part of its energy-absorption capacity under repeated heavy loadings.

5.4.4 Fender System Design.

5.4.4.1 Ship Contact. While the ideal berthing process would attempt to engage as many fender units as possible, in reality, at the time of impact, the ship will be at a slight angle to the berth and contact will be made over a small length. Discrete fender units such as the buckling column type or the floating type should be designed for one unit providing the full energy with a minimum of two units installed per berth. For the continuous system using flexible piles and rubbers, the length of contact will be a function of the ship's hull radius at the level where contact is made, the flexibility and spacing of rubber fender unit units, and the stiffness of the chock and waler assembly in the horizontal plane. The problem is analogous to a beam on elastic foundation. In the absence of more rigorous analysis, the following assumptions for contact length may be made:

Cruisers, destroyers, and frigates ..... 20 ft

Battleships, amphibious warfare
ships, and auxiliary ships .... 40 ft

When berthing is made with separators, only one separator should be assumed to be in contact at the time of impact, with a minimum of two separators installed per berth. Where the separators are guided by fender piles, all the piles may be assumed to be effective in sharing the energy. When free-floating separators are used, not all the piles backing the separator will be effective. Local experience should dictate and a more conservative assumption should be made.

5.4.4.2 Allowable Hull Pressure. When the ship's energy is resisted through foam-filled or pneumatic fenders, the resulting force is concentrated in a small area of the ship's hull. In such cases, the allowable pressure on the ship's hull becomes a critical design issue. Most fast combatants have a thin hull plating with a low allowable hull pressure. Table 7 lists typical values for some ship types. For more specific information on the ships being berthed, NAVSEASYSCOM should be consulted. **See TR-6015-OCN, , "Foam Filled Fender Design to Prevent Hull Damage", for additional information.** The values in Table 7 are based on yielding of the hull plating and include a 1.5 safety factor. Consequently, when checking for an accidental condition, the allowable value may be increased by up to 50 percent. {INSERT TABLE & FIGURE FROM TR-6015??}

5.4.4.3 Allowable Stresses. ~~Since~~Because ship berthing is a short-term impact type of loading, the following increases over published values (MIL-HDBK-1002/5, MIL-HDBK-1002/6, NAVFAC DM-2.03, and NAVFAC DM-2.04) are permitted. The fender system may be designed as a Class B structure.

a) Timber. For operating condition, the allowable stress in flexure (tension and compression) may be taken as 0.67 X modulas of rupture or the published allowable values increased by a factor of 2.0, whichever is less. For the accidental condition, the stress-strain curve may be assumed to be linear up to 0.9 X modulus of rupture, which should be taken as the limit.

b) Steel. For operating condition, the allowable stress in flexure (tension and compression) may be taken as 0.8 X yield stress. For the accidental condition, full yield stress may be used. However, the sections used should satisfy compactness requirements or the allowable stress reduced proportionately. Members should be sufficiently braced for development of the yield strength.

c) Concrete. Reinforced and prestressed concrete members not intended for energy absorption should be designed with a load factor of 1.7 over forces developed due to operating condition. When designed thus, they will be satisfactory for the accidental condition. Further prestressed members should not be allowed to develop tensile stresses in excess of 12 X square root of 28-day compressive strength in the precompressed zone. Prestressed concrete members specifically designed for energy absorption may not conform to the above requirements and are beyond the scope of this manual. {See NFESC TR-????? For guidance on the design of prestressed concrete piles for use as fender piles.}

~~Change 2, 28 February 1992~~

Table 7

Maximum Allowable Hull Contact Pressures[*]

Typical Vessel Type	Designation	Class	Max. Allowable Hull Contact Pressure at Waterline (psi)
Battleship	BB 61	Iowa	17.3
Guided missile cruiser	CG 26	Belknap	17.3
Guided missile cruiser	CG 47	Ticonderoga	9.3
Guided missile cruiser	CGN 36	California	19.0
Guided missile cruiser	CGN 38	Virginia	18.7
Aircraft carrier	CV 66	Kitty Hawk	34.8
Aircraft carrier	CVN 68	Nimitz	28.9
Destroyer	DD 963	Spruance	9.3
Guided missile destroyer	DDG 2	Adams	32.0
Guided missile destroyer	DDG 37	Farragut	30.0
Guided missile destroyer	DDG 993	Kidd	9.3
Frigate	FF 1052	Knox	10.0
Guided missile frigate	FFG 7	Oliver Hazard Perry	9.3
Submarine	SSN 637	Sturgeon	15.2
Submarine	SSN 688	Los Angeles	27.2
Ballistic missile submarine	SSBN 616	Lafayette	15.2
Ballistic missile submarine	SSBN 726	Ohio	30.3
Minesweeper	MSO 427	Constant	4.7[**]
Amphibious cargo ship	LKA 113	Charleston	12.6
Amphibious transport dock	LPD 4	Austin	12.8
Amphibious assault ship	LHA 1	Tarawa	17.6
Dock landing ship	LSD 36	Anchorage	18.5
Tank landing ship	LST 1179	Newport	10.0
Destroyer tender	AD 37	Samuel Gompers	9.4
Ammunition ship	AE 26	Kilauea	14.6
Combat store ship	AFS 1	Mars	18.1
Fast combat support ship	AOE 1	Sacramento	17.6
Oiler	AO 177	Cimarron	21.0
Oiler	AO 187	Henry J. Kaiser	19.9
Replenishment oiler	AOR 1	Wichita	27.7
Salvage ship	ARS 38	Bolster	13.4
Salvage ship	ARS 50	Safeguard	13.4
Submarine tender	AS 36	L.Y. Spear	9.2
Repair ship	AR 5	Vulcan	11.8

[*] The allowable pressure is based on contact at the middle 60 percent of ship's length at waterline.

[**] Assumed value. MSO has a wooden hull capable of accepting high contact pressures.

~~_Change 2, 28 February 1992~~

5.4.4.4 Coefficient of Friction. As the ship is berthed against the fender system, there will be force components developed in the longitudinal and vertical directions also. As the coefficient of friction between rubber and steel is very high, special fender front panels have been developed with reduced friction coefficient. Ultra high molecular weight (UHMW) plastic rubbing strips have been successfully used in front of timber piles. The following friction coefficients may be used in the design of fender systems.

Timber to steel	0.4 to 0.6
Urethane to steel..............	0.4 to 0.6
Steel to steel	0.25
Rubber to steel	0.6 to 0.7
UHMW to steel	0.1 to 0.2

5.4.4.5 Temperature Effects. Fender piles, backing members, etc., are not affected by temperature fluctuations and can be expected to perform normally. However, in colder temperatures, rubber fender units become stiffer and their performance will be affected significantly. Hence, the energy-absorbing capability of the rubber unit and the fender system as a whole should be evaluated based on the lowest operating temperature expected. UHMW rubbing strips which have a significantly higher rate of expansion than steel or concrete should also be carefully designed and detailed to operate effectively.

5.4.5 Corner Protection. All corners of piers and wharves and entrances to slips should be provided with fender piles, rubbing strips, and rubber fenders for accidental contact with ships or routine contact with tugs. See Figure 57 for typical details.

5.4.6 Support Chains. Chains are commonly used in fender systems when a tension member is needed. Chains are used in continuous fender systems and large buckling and cell type units to resist the sudden energy released. For pneumatic and foam-filled resilient fender units, the chain is used to suspend the units. Chain smaller than 3/8 inch is not recommended. For better corrosion resistance, zinc coating is preferred. A common weldless high-test chain is usually more cost-effective than the stud link variety.

5.5 Maintenance of Fendering Systems. For a fender system to perform as designed, it is essential that all components of the system be maintained, including piles, rubber components, mounting bolts, support/shear chains, shackles,face panels and low friction pads. Failure of key components could result in expensive damage to the ship, pier or wharf, or the other components of the fender system. All fenders should be regularly inspected and damaged components replaced as soon as possible. Torn or punctured skins of foam filled or pneumatic fenders should be immediately repaired to avoid enlargement of the damaged area and total failure of the fender. Manufacturer's repair kits for the urethane skins may be available. Mounting plates imbedded in the molded rubber carcass of buckling type fenders may be exposed to the elements due to cracks in the rubber. This allows air an water to reach the steel thereby promoting corrosion of the steel. Cracks or cuts should be sealed to extend the life of the fender element. Damage to shear chains could allow lateral failure of the entire fender system. Broken fender piles will not only accelerated damage to the adjacent piles, but could cause damage to the ships. Coatings on steel elements of fender systems should be cleaned and touched up to extend the useful life of the system. Deterioration of chocks and wales in a pile type fender system must be maintained to prevent failure of the entire system.

~~Change 2, 28 February 1992~~

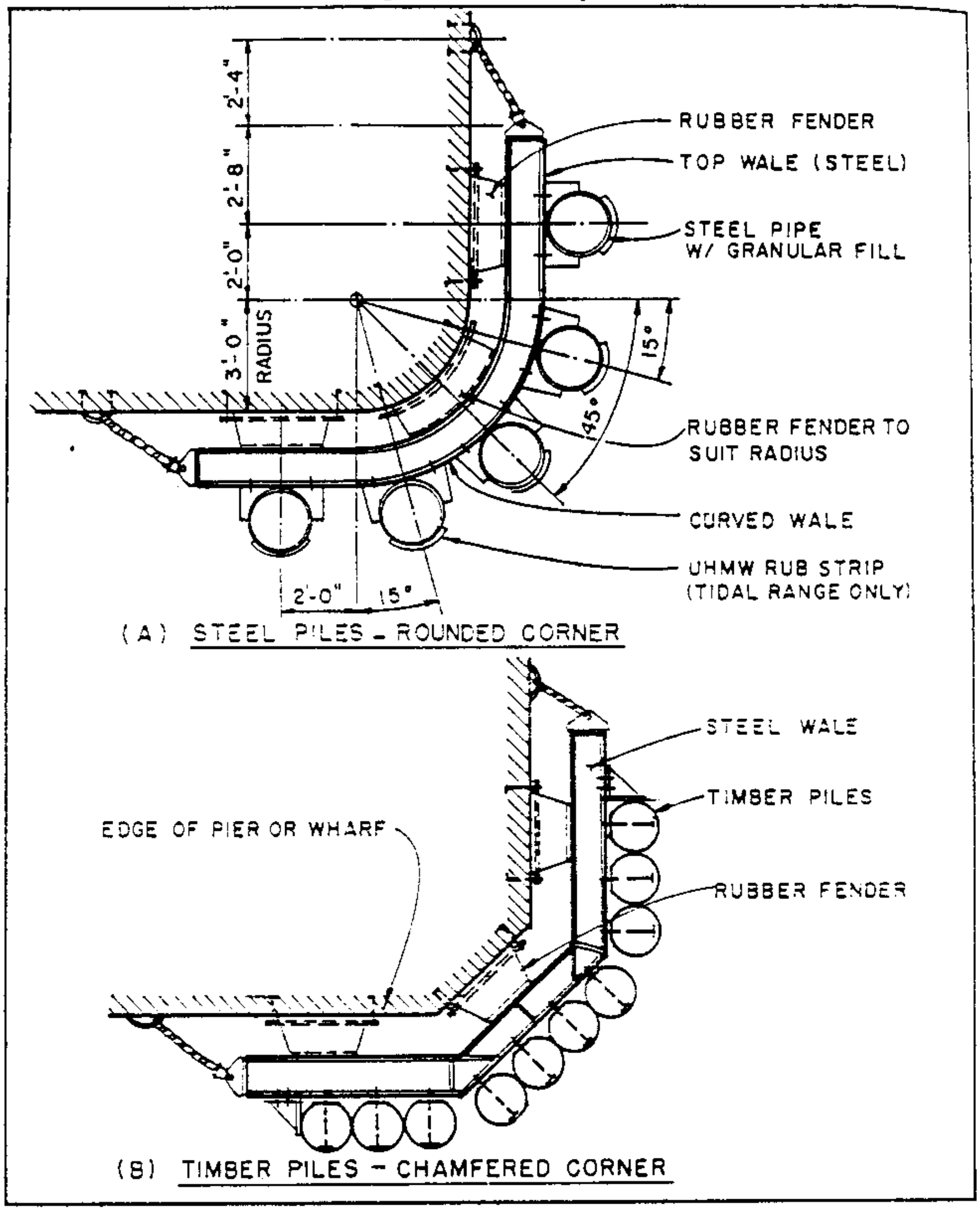

Figure 57
Corner Protection

Section 6. SEPARATORS

6.1 Function and Application. Separators are devices used between the ship and the structure or between adjacent multiple berthed ships to provide a "standoff" or separation. A separator used between a ship and a dock is frequently referred to as a camel. All Navy piers use separators extensively for the following reasons:

6.1.1 Hull Maintenance. During active berthing, the ship's crew typically performs cleaning, painting, light hull repairs, and other routine maintenance activities on the ship. These activities are best performed when the ship is kept off the structure at discrete points.

6.1.2 Overhangs and projections. Aircraft carriers that have large overhangs at the flight deck level, and several other ship types having bulges and projections at the side, require separators to prevent damage to the ship at these projections. Other protrusions include air masker bands, soft sonar domes, and stabilizer fins.

6.1.3 Special Skin Treatments. New classes of ships are being equipped with special hull treatments that can get damaged through constant rubbing against the structure. Separators with special rubbing strips can minimize the contact area and control the damage.

6.1.4 Submarine Berthing. Navy submarines are typically berthed with deep-draft (camel) separators. The submarines may be moored to the camels or moored directly to the berthing structure. Submarines require the separators to prevent damage to diving planes, screws, fairings, and the special skin treatments.

6.1.5 Multiple Berthing. Separators are required between ships that have to be berthed abreast for ship-to-ship transfer operations or for lack of berthing space in the naval station.

6.1.6 Fender Protection. When the existing fender system can suffer damage due to motions of moored ships, a separator can be useful in reducing the damage as long as it is properly placed and the ship is properly moored. If not, camels can easily increase the damage to timber fender piles.

6.2 Separator Types The more commonly used separator types are as follows:

6.2.1 Log Camels. These are large-diameter turned timber logs (24- to 36-inch diameter 40 to 50 ft long, held in the desired position from the deck by nylon ropes or chains. They are usually allowed to float with the tide. The longer length is preferred as they can distribute the load to a greater number of piles. See Figure 58(A).

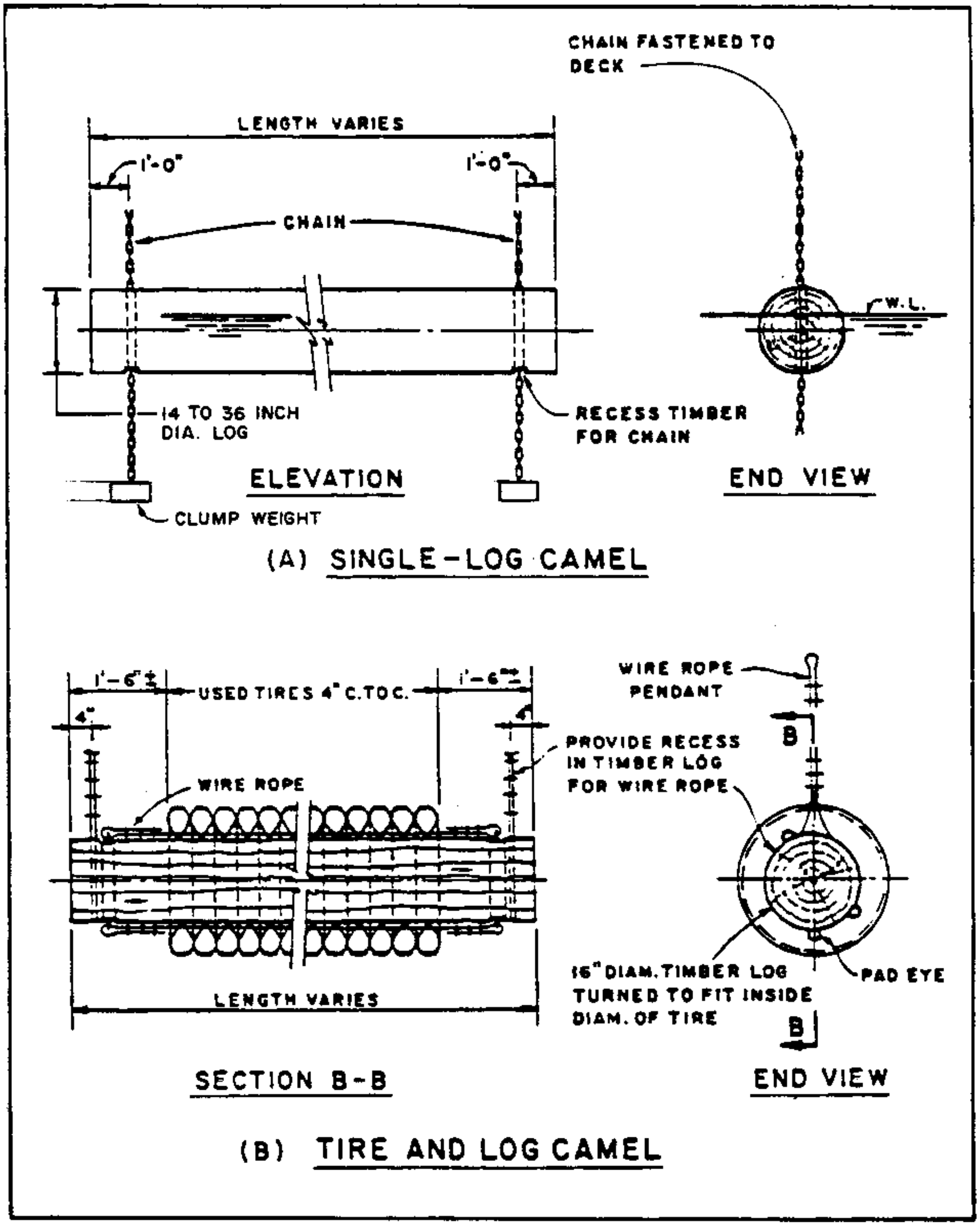

Figure 58
Log Camels

ADD SECTION OF COMPOSITE LOG CAMEL?

Multiple log camels are made from several smaller diameter logs held together by wire rope at ends and at center. They are not as efficient as the single log camels. Log camels fabricated from recycled plastics and composite materials are available. Sometimes a series of used tires may be fitted through the log to provide some energy absorption, as shown in Figure 58(B). Log camels do not provide much of a separation. When a wider separation is needed, a steel, ~~or~~ wood, or composite pontoon camel may be inserted between the ship and log camel.

6.2.2 Timber Camels. These consist of several large timbers connected together by struts and cross braces to form a large crib. Additional ~~foam~~ flotation units may be inserted between the timbers for a higher freeboard. Wear causes bolt heads to become exposed and thus cause damage to hulls. See Figure 59(A).

6.2.3 Steel Pontoon Camels. These are made of cubical or cylindrical steel pontoons connected by structural framing. The pontoons should preferably be filled with foam to reduce the risk of losing flotation by accidental puncturing of the units. See Figure 59(B). Figure **??** shows an aircraft carrier camel constructed of welded steel tubes combined with foam-filled fenders along the dock side face to provide energy absorbtion and cushioning for ship movements at berth. Note that the lower profile edge of the camel is placed against the ship's hull to avoid interference with the framing for the ship's aircraft elevators when in the lowered position. UHMW polyethelene pads are provided along the ship contact edge of the camel to reduce the coeficient of friction.

6.2.4 Deep-Draft Camels. For submarine berthing where a good portion of the body is below the waterline, all the above camels are inadequate as the camel will ride up on the submarine during berthing. Hence, deep-draft camels made from large steel pipes and timber walers have been developed. See Figures 60 and 61. They have a limited energy absorption and a narrow working platform. These camels work well when mooring against a tender ship and for multiple berthing. When used against an open pier or wharf, these camels will require solid backing elements (below waterline) from the fender system. The more advanced version of the submarine camels is used for berthing the Ohio-class (Trident) submarines. These camels are attached to guide piles and provided with a large working deck. See Figure 42. The submarine is moored to the camels with preventer lines (at bow and stern cleats) going directly to the wharf structure. The guided camel arrangement is recommended where the submarine has a dedicated berth.

6.2.5 Hydro-Pneumatic Fenders. Another type of deep draft fender used for berthing of submarines is the hydro-pneumatic fender discussed in 5.3.2.6.

6.2.6 Composite Camels. NFESC is developing a composite camel for berthing of submarines – see Figure **???**. This concept uses 18-inch composite back-up piles spliced to steel H-piles. There is a composite "tub" for guiding the piles and tying the piles together. The configuration of the camel is intended to serve both current and future generations of submarines. By connecting two of these composite camels back to back, a separator for use between two submarines is formed.

6.2.7~~5~~ Carrier Camels. Aircraft carriers, with their large overhang at flight deck, require a wide separator from the pier or wharf structure. A special steel-framed camel has been developed for this use and is illustrated in Figures 62 and **??**.

6.2.8~~6~~ Large Fenders. Foam-filled fenders and large cell-type fenders can serve as separators to provide the standoff for some ship types. Foam-filled and pneumatic fenders can also be used as a separator between ships in multiple berthing, as shown in Figure 63.

6.3 Loads. The camel loads are computed from berthing and mooring analysis of the ship, camel, fender, and structure system resisting the lateral loads. See MIL-HDBK 1026/4, Mooring Design, for guidance on computing the forces from wind and current. All the ship's current and wind loads are transmitted through the camels to the pier or wharf structure. All horizontal loads may be assumed to be acting uniformly along the length. Deck elements of large camels should be designed for 50-psf vertical live load. The camel assembly for fabricated camels should be checked for lifting stresses. Where the pick-up points and rigging configurations are critical to control lifting stresses in the camels, provide clearly marked pick-up points or pad-eyes. For complex lifting requirements, lifting diagrams should be provided on the design drawings.

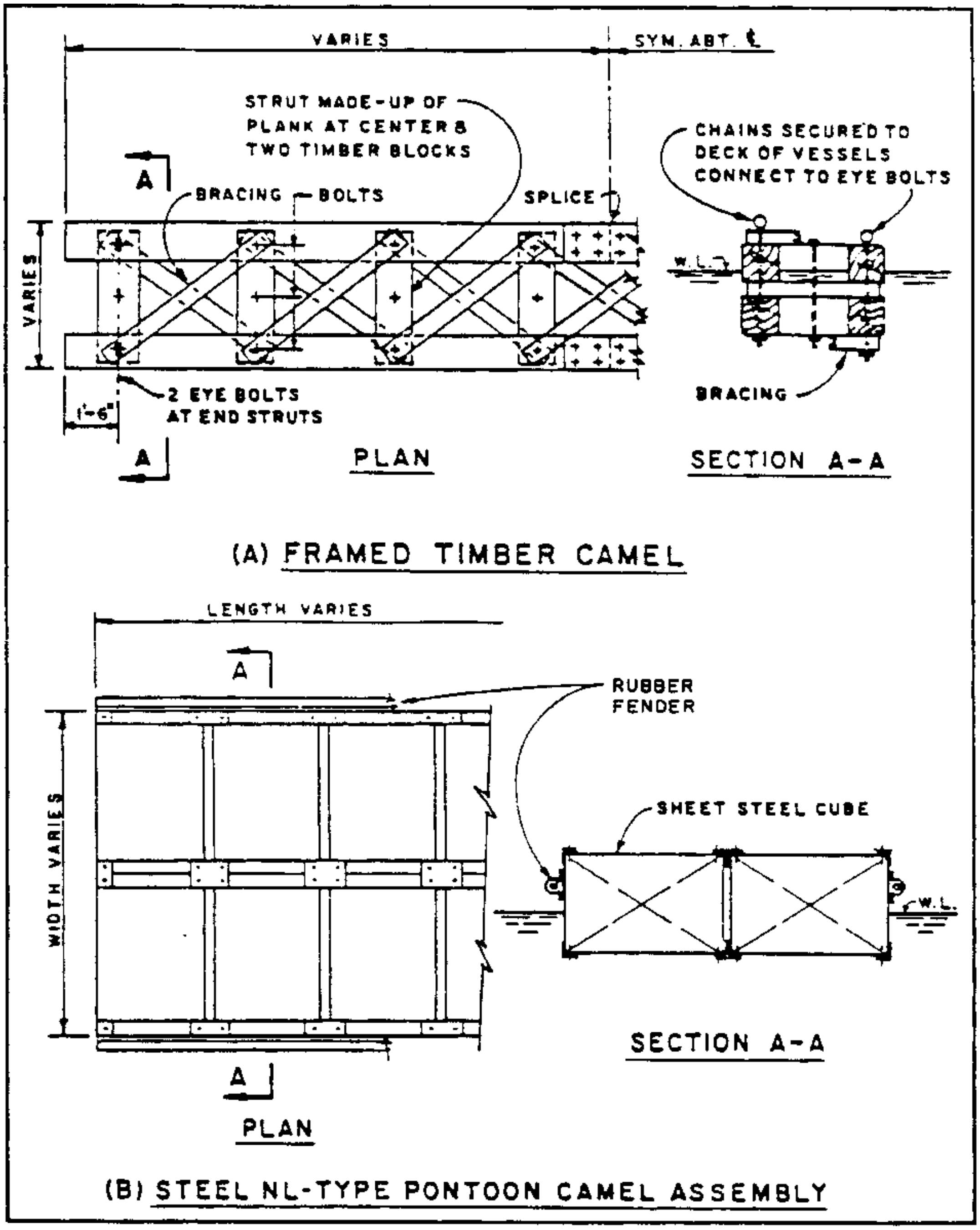

Figure 59
Timber and Steel Pontoon Camels

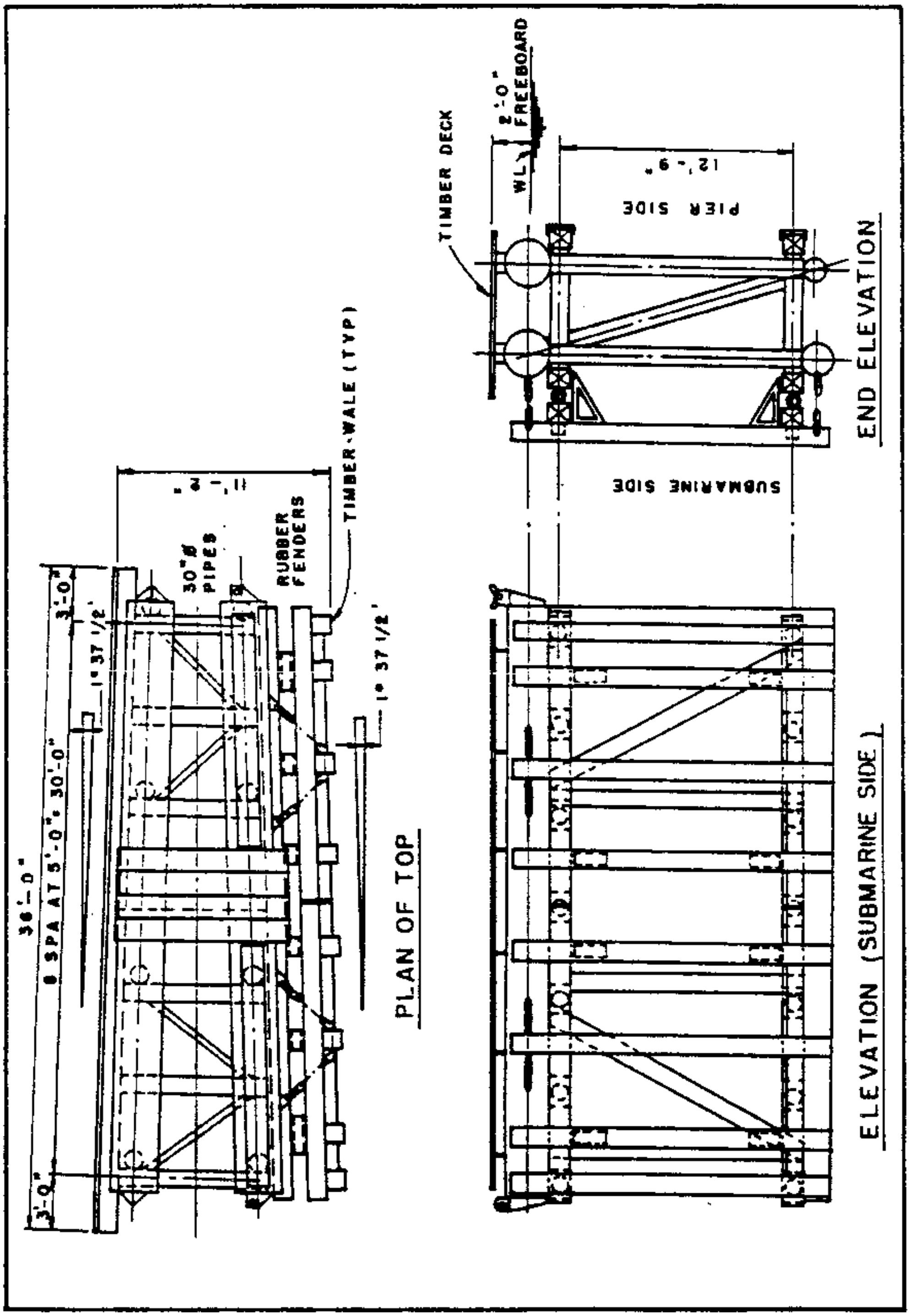

Figure 60
Deep-Draft Camel for Submarines

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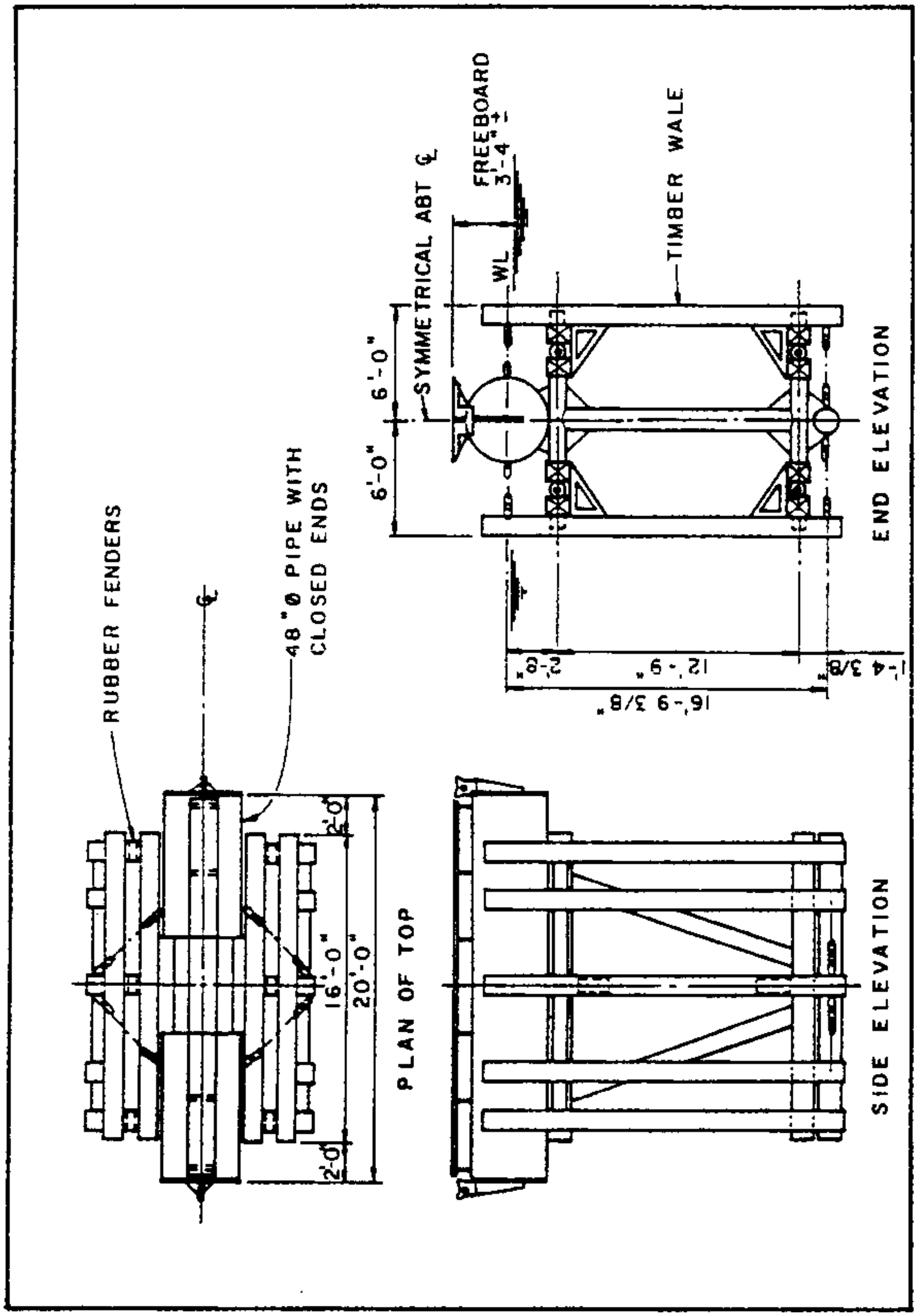

Figure 61
Deep-Draft Separator for Submarines

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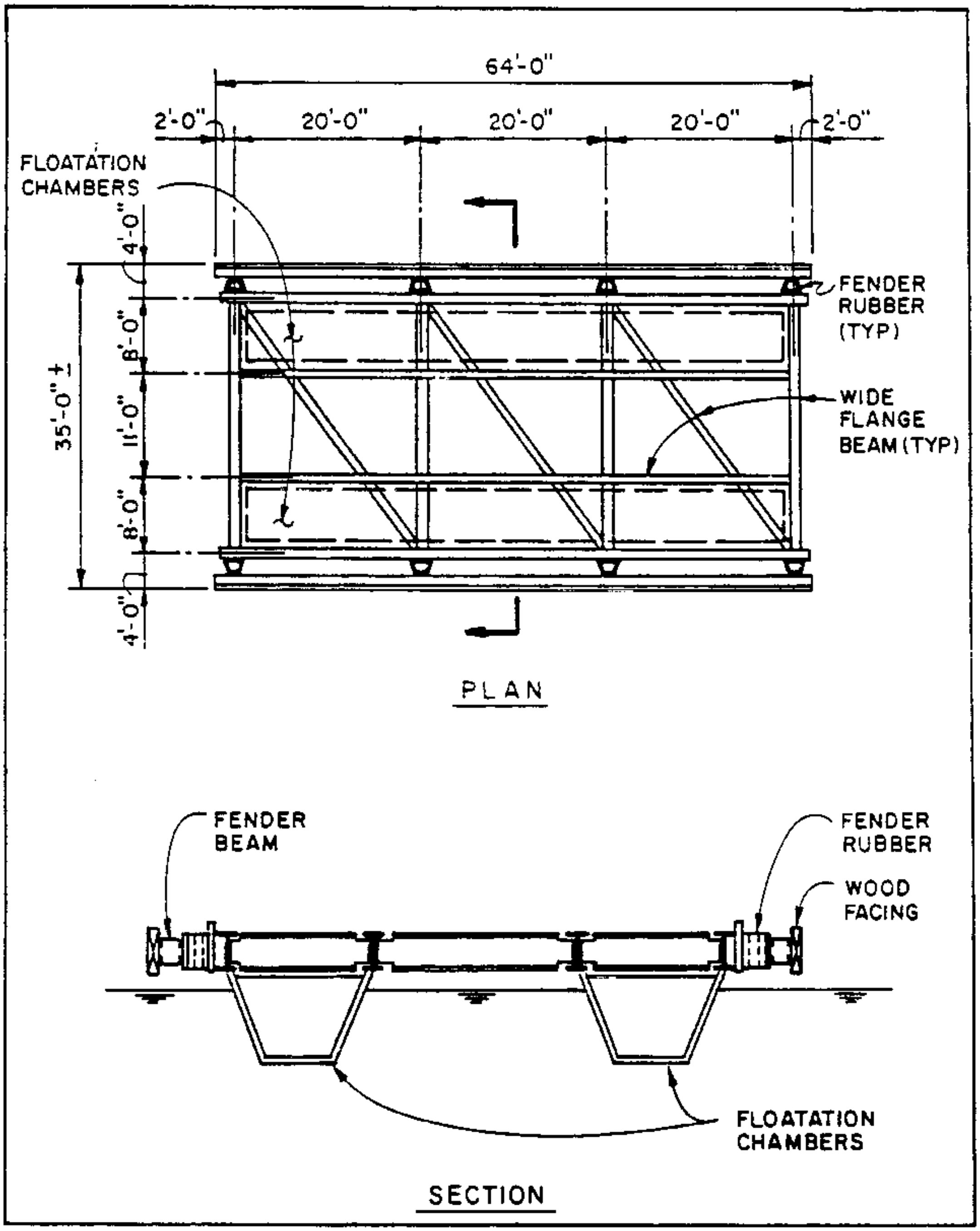

Figure 62
Carrier Camel

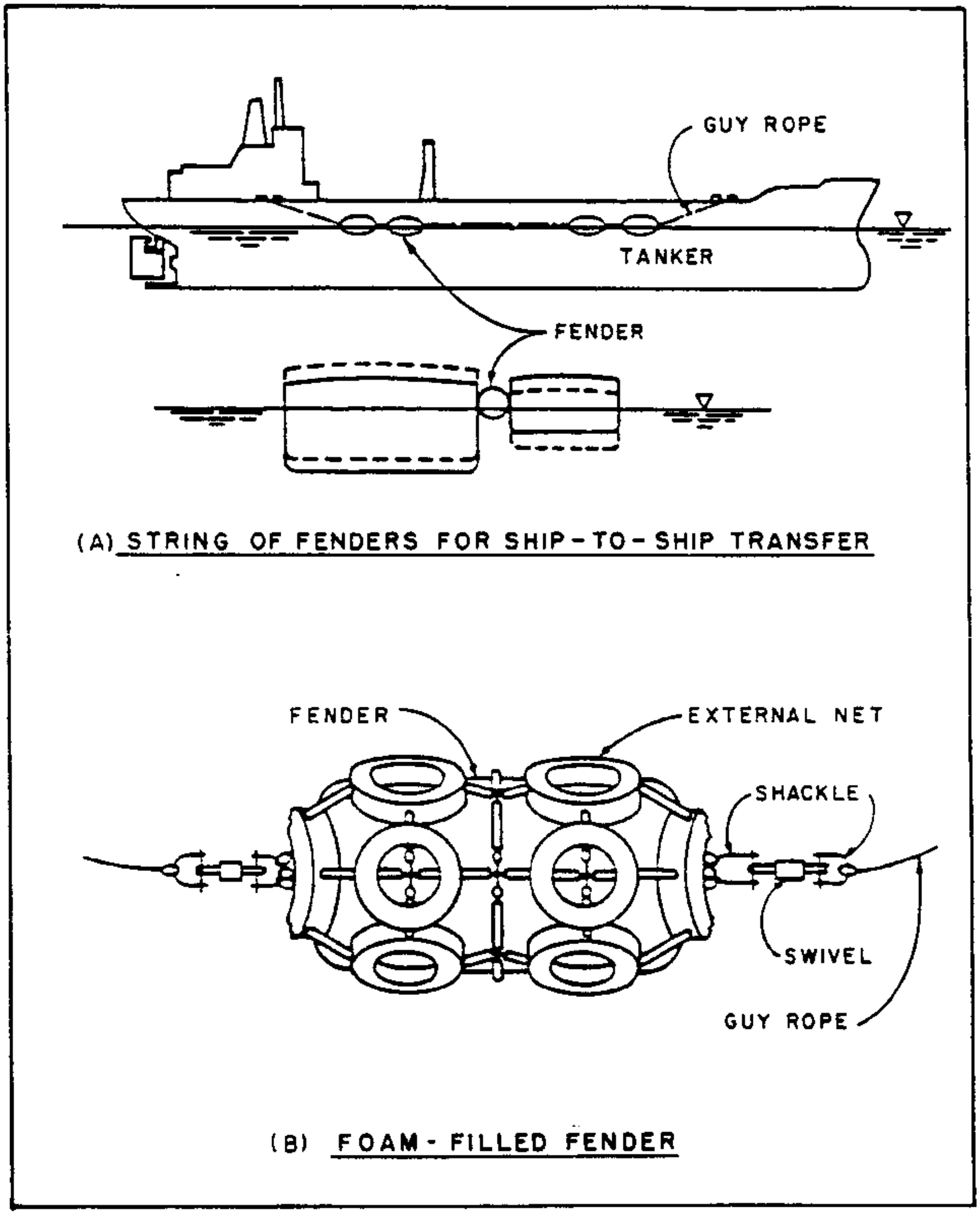

Figure 63
Foam-Filled Fender as Separator

6.4 Geometry. The shape and size of fabricated camels are governed ship's geometry at waterline.

6.4.1 Ship's Lines. For large vessels such as CVs or CVNs, camels may be designed for berthing a single class of ship. The bearing face between camel and vessel should be shaped to approximate the lines of the ship at waterline. Because hull lines vary with conditions of draft and trim, generally only a rough match is possible. Therefore, the outboard camel bearing face should be provided with rubber fenders or other means to produce some flexibility in the bearing face, thus compensating for minor hull line variations. Where hull line variations are large, adapters or telescoping devices may be required. Except for straight-sided ships, usually a single line bearing between separators and ships is provided.

6.4.2 Length and Width. Adequate length of separators should be provided in order to keep the contact pressure between separator and hull and between separator and pier fenders within allowable limits. This is particularly important where compressible fender faces are used that transfer reaction pressure directly to the hull plate versus the frames of the vessel. The length should not be less than the distance between three frames of the ship, three fenders or fender piles on the pier, or 30 ft, whichever is greatest. Minimum separator width is determined by the ship's roll characteristics and freeboard, ~~and~~ the presence of any overhanging projections on a ship and vertical obstructions on the dock such as gantry cranes or light poles.

6.4.3 Depth. Adequate depth should be provided for submarine camels and separators to maintain contact with ship and dock in the full tidal range.

6.5 Stability. There is usually some eccentricity between the horizontal load applied on the ship side and the horizontal reaction provided on the dock side. This is due to tilting of the camels (from imperfect floatation, buoyancy tank taking on water, etc.) and tendency of the camel to ride up and down with the vessel due to tidal fluctuations. The camel should have sufficient width, depth, and weight to provide roll stability for counteracting the effect of the load eccentricity and should have means of adjusting for variations in tilt and trim. Providing a lower level frame as shown in Figure **??** can be effective in limiting the tendency of a camel to flip. **{insert a figure illustrating the effect of eccentricity and the control provided by a lower level frame}**

6.6 Location. For fine-lined ships, camels should generally be placed within quarter points of the ship to give strength and to bear on a reasonably straight portion of the hull. For straight-sided ships, camels may be located beyond the quarter points. At least two camels should be provided for all classes of ships. In any event, camels should not be placed so as to bear directly against structural piles.

6.7 Miscellaneous Considerations

6.7.1 Protection. Consideration should be given to outfitting steel separators with a suitable protective coating or a cathodic protection system, depending on relative costs.

6.7.2 Buoyancy Tanks. Buoyancy tanks should be compartmented or foam filled. Drainage plugs used for pressure testing the buoyancy tanks should be provided. Where pontoon camels are assembled in a single line, they should be ballasted for stability through plugged openings provided for this purpose. The buoyancy of framing members and the weight of paint, if any, should be considered in the buoyancy and stability computations. Where buoyancy tanks are not foam filled to allow filling with balast water or weights to adjust trim and freeboard of the camel, easily accessible fill/pumpout and vent connections should be provided. These connections can be used to pumping out excess water that leaks into the tanks.

6.7.3 Abrasion. Camel fenders rubbing against a hull remove its paint. Exposed surfaces are subject to corrosive action, especially at the waterline. For these reasons, it is desirable to have camel fenders rub against hulls above the waterline where the hull can be repainted if necessary.

RECOMMEND THAT THE FOLLOWING ADDITIONAL FIGURES BE ADDED TO THIS SECTION AND REFERENCED IN THE APPROPRIATE PARAGRAPHS:

Camel lifting diagram from NAVFAC Dwg. No. 5358508
Typical Camel Section from NAVFAC Dwg. No. 5358513
Submarine camel perspective illustration from NAVFAC Dwg. No. 1404667
Camel Arrangment Diagrams from NAVFAC Dwg. No. 1404667
Submarine Camel Plan & Section from NAVFAC Dwgs. Nos. 1404944 & 1404945
Illustration of “Deep Draft Submarine Camel”, Figure 2 from NFESC/Duane Davis’s report on Advanced Fendering Systems, 30 March, 1999.
Illustration of “Deep Draft Submarine Separator – Two Camels Joined Together”, Figure 3 from NFESC/Duane Davis’s report on Advanced Fendering Systems, 30 March, 1999.
Sectional drawing of a Hydro-Pneumatic Fender, “detail of Pier 5003 Fender” from NFESC/Duane Davis’s report on Advanced Fendering Systems, 30 March, 1999.

Section 7. ACCESS FACILITIES

7.1 General. Several access structures are used in piers and wharves for moving personnel and cargo, and accommodating selected utility lines. They have unique design requirements. Some are of standard design and may be procured as collateral equipment while others are designed and constructed specifically to go with the facility. The access facilities covered by this manual are landing float, brow or gangway, brow platform, walkway or catwalk, ramp, and utility boom.

7.2 Landing Float. When piers and wharves need to be accessed from the waterside by small craft such as patrol boats (which cannot berth directly), a landing float and a brow are required.

7.2.1 Materials. Flotation units may consist of foams of polystyrene and polyurethane, fiberglass-reinforced polyester resin shells with or without foam cores, metal pontoons, metal pipes, metal drums, and hollow concrete sections. Timber logs, the earliest form of flotation unit and the cheapest, have a tendency to become waterlogged and their use is not recommended. Decks of floats are variously made out of wood planks, plywood, plywood and fiberglass-resin coatings, concrete, and nonskid metal surfaces. Framework for floats is generally of preservative-treated timber, although steel and aluminum are often used. All ferrous metal hardware should be galvanized or otherwise protected from corrosion.

7.2.2 Mooring Systems. Floats should be anchored to prevent movement by wind, current, waves and impact from the ships. Anchorage may consist of individual vertical (guide) piles, frames of batter and vertical piles, and cables or chains. See Figure 29. When piles are used to anchor small floats, guides are furnished to secure the float to the anchor pile. Commonly used guides are rigidly braced metal hoops of pipes, rollers, or traveler irons. Chains and flat bar guides should not be used as they cause the float to hang up on the piles. See Figure 64 for details. This system works well for shallow waters with a large tidal range. In deeper water, the pile head may have to be supported by the structure or pile driven deeper. Anchorage may also be obtained from a cable or chain system attached to the ocean bottom or to the fixed pier or wharf structure.

7.2.3 Live Loads. Stages for landing personnel only are designed for a uniform live load of 50 lbs/ft^2 or a concentrated live load of 500 lbs placed at any point on the deck surface. The float should not tilt more than 6 deg. from the horizontal when applying the concentrated live load of 500 lbs.

7.2.4 Freeboard. Floating stages for small craft usually ride with the deck from 15 to 20 in. above the water surface under dead load. Live loads usually lower the float about 8 to 10 in.

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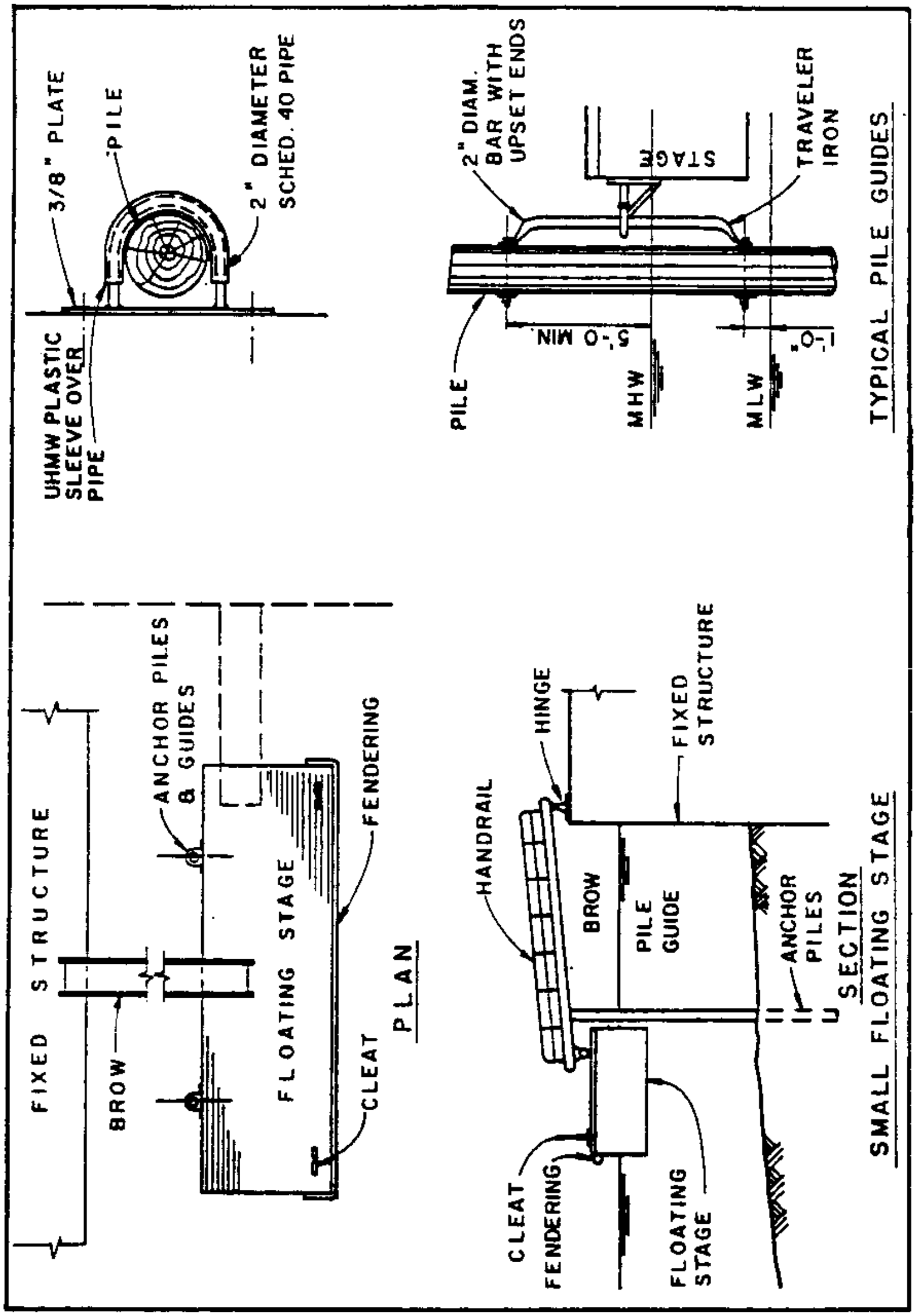

Figure 64
Small Floating Stage

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7.2.5 Fendering. Fenders should be provided on all floating stages. For small craft berthing, fenders may consist of soft, flexible rubbing strips (rubber tires, sections of hose).

7.2.6 Fittings. A minimum of three cleats (5,000-lb. capacity) should be provided for securing small craft.

7.2.7 Finish. The deck should be provided with a nonskid surface. Where wheels or rollers from a brow will be resting on the float, guide channels or a skid plate should be provided to prevent damage to the float.

7.2.8 Reinforced Plastic Landing Float. The float shown in Figure 65 is constructed of a planking material, referred to as "rovon planks," formed by wrapping glass roving, spirally, around rigid polyurethane foam cores. For extra strength, several wrappings may be applied. The float is 60 ft long, 14 ft wide, and 5 ft 4 in. deep. It weighs about 26,000 lbs. The deck is covered with a nonskid coating. In unloaded condition, the float draws 2 ft 1 in. of water and in load condition the float, designed for a uniform live load of 100 lbs/ft^2 or a concentrated load of 500 lbs placed at any point on the deck, draws 3 ft 7 in. of water. Cleats and a timber fender system are provided. A 12- by 12-in. timber member is attached at each end to receive timber pile guides located at each corner. For additional details, refer to ~~NCEL~~ NFESC Technical Report R 605, Reinforced Plastic Landing Float and Brow. The float is light, strong, and has a high roll stability due to the catamaran-type hull construction.

7.2.9 Concrete Float Elements. Concrete encased plastic foam elements design for use in concrete floating docks for marinas can be connected together in various configurations to be used as work floats. The mass added by the concrete encasement creates a very durable float that is less affected by waves and live loads than more light weight systems.

7.3 Brow or Gangway. Brows are used for access to landing floats from the pier or wharf structure. They are more frequently needed to access a berthed ship from the deck. Brows are primarily used for personnel movement to or from the ship. NAVFAC standard brow drawings are available from the engineering field divisions. Where there is a potential need for access to a facility by physically handicapped persons, ramp slopes and widths and landings should meet the applicable requirements of the Americans with Disabilities Act Accessibility Guidelines (28 CFR part 36, Appendix A).

7.3.1 Length. Brows should be of sufficient length so that the slope will not exceed 1.5 horizontal to 1.0 vertical at the worst condition.

7.3.2 Widths. Widths should be 36-in. minimum (clear) passage for one-way traffic and 48-in. minimum (clear) passage for two-way traffic. A 60-in. minimum (clear) passage should be provided for two-way traffic when personnel carry small loads.

7.3.3 Construction. Fiberglass, aluminum, steel, timber, or a combination of these materials may be used. Aluminum and fiberglass are generally preferred for the low weight to strength ratio and corrosion protection.

7.3.4 Live Load. The brow structure should be designed for a uniform live load of 75 lbs./ft^2 and a concentrated live load of 200 lbs. applied anywhere. A reduction in the live load to 50 lbs./ft^2 may be permissible where the brow is to be used in conjunction with a landing float. For calculation of reaction to the landing float, the live load can further be reduced to 25 lbs./ft^2.

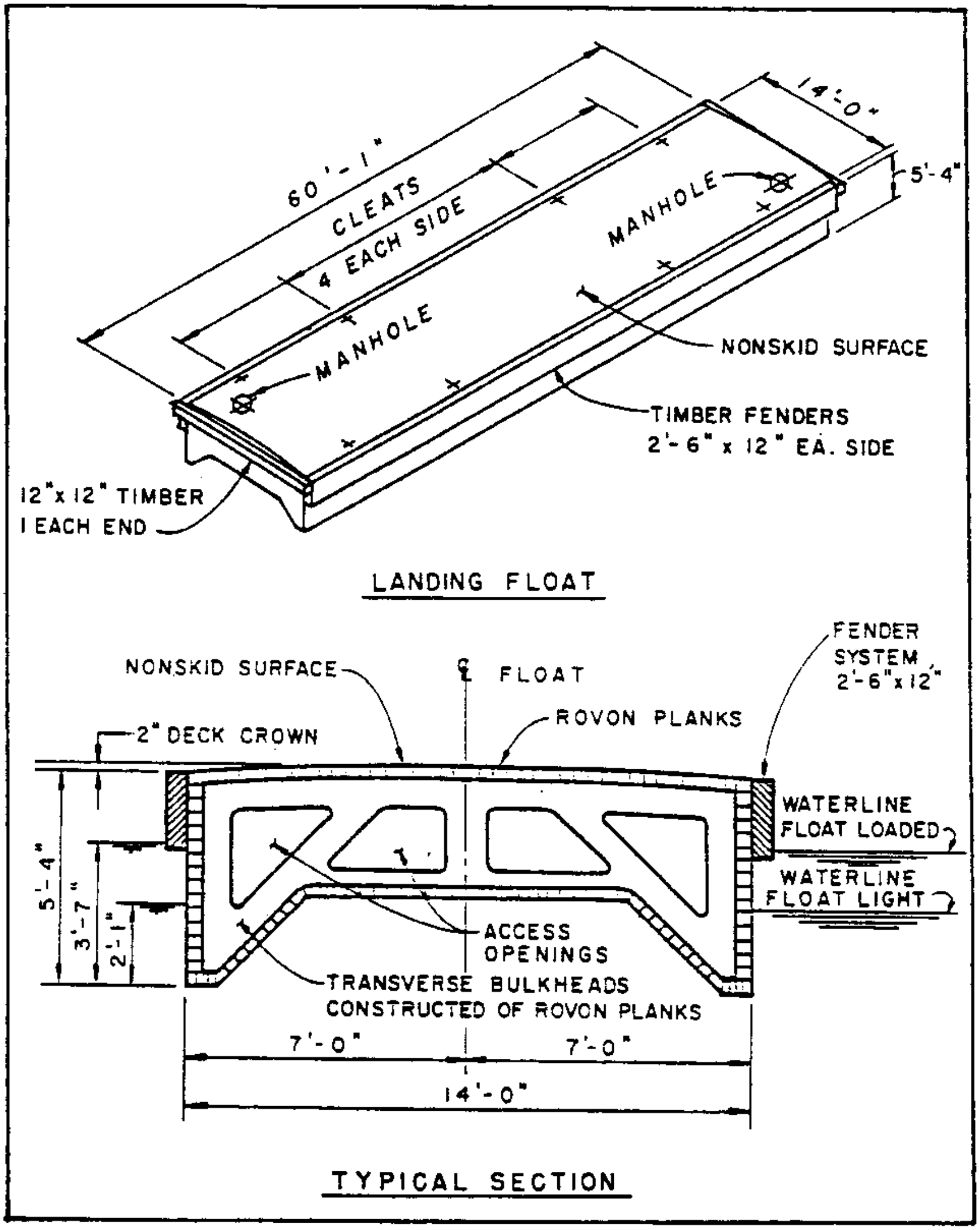

Figure 65
Reinforced Plastic Landing Float

7.3.5 Handrails. Handrails designed for 20 lbs. per lineal foot lateral load should be provided on either side of the brow. The handrail may be designed to serve as the top chord of a truss when sufficiently braced.

7.3.6 Safety. Safety devices should be provided to keep the brow from rolling off the platform deck and to prevent movement of the platform while in use. Safety chains should be clipped into position for personnel safety. Large tidal variations are a problem because these may cause the brow to roll off the platform. A similar situation exists when high winds, currents, and extreme tides pull a ship away from the pier.

7.4 Brow Platforms. These are used when a brow from ship deck to pier deck is not practical, or presents an obstruction. Examples are portal crane trackage along repair berths, large tidal variations, and great height from deck to pier. Aircraft carriers (CVs and CVNs) usually use one brow forward and two aft. These brows require platforms 20 ft or higher. This platform is basically a truncated tower, with typical measurements of 12 x 12 ft at the base, while the top deck is 5 ft wide and 10 ft long. If small stair platforms are built alternately opposite hand, the requirement for a large platform can be met by lashing two of the smaller ones together. See Figure 66. Sometimes the ship end of the brow can be connected to a rotatable platform which is permanently fixed to the ship by means of pins that lock the brow pivot hooks to the circular rotating portion of the rotatable platform. See Figure 67. Construction materials and live load requirements are the same as for brows.

7.5 Walkway or Catwalk. These are permanent personnel access bridges installed between shore and different elements of piers and wharves. One example is a walkway between the pier or wharf structure and a mooring dolphin located some distance away (shown in Figure 1). Where there is a potential need for access to a facility by physically handicapped persons, ramp slopes and widths and landings should meet the applicable requirements of the Americans with Disabilities Act Accessibility Guidelines (28 CFR part 36, Appendix A).

7.5.1 Width. For walkways between shore and a U-shaped wharf, a 4-ft width is recommended. For infrequently used walkways, the minimum width should be 3 ft.

7.5.2 Live Load. All walkway structures should be designed for 100 lbs./ft^2 live load.

7.5.3 Construction. Walkway decking should be slip-resistant aluminum or fiberglass grating. Framing may be wood, aluminum, or fiberglass members. In view of the light loads encountered, piles supporting deck stringers can be of treated timber. Where loads and installation difficulty make timber piles inadequate, concrete and steel piles may be used.

7.5.4 Handrails. Handrails should be provided on either side of the walkway. Handrails should also be considered for use along edges of approach trestles and along non-berthing extents of docks or wharves.

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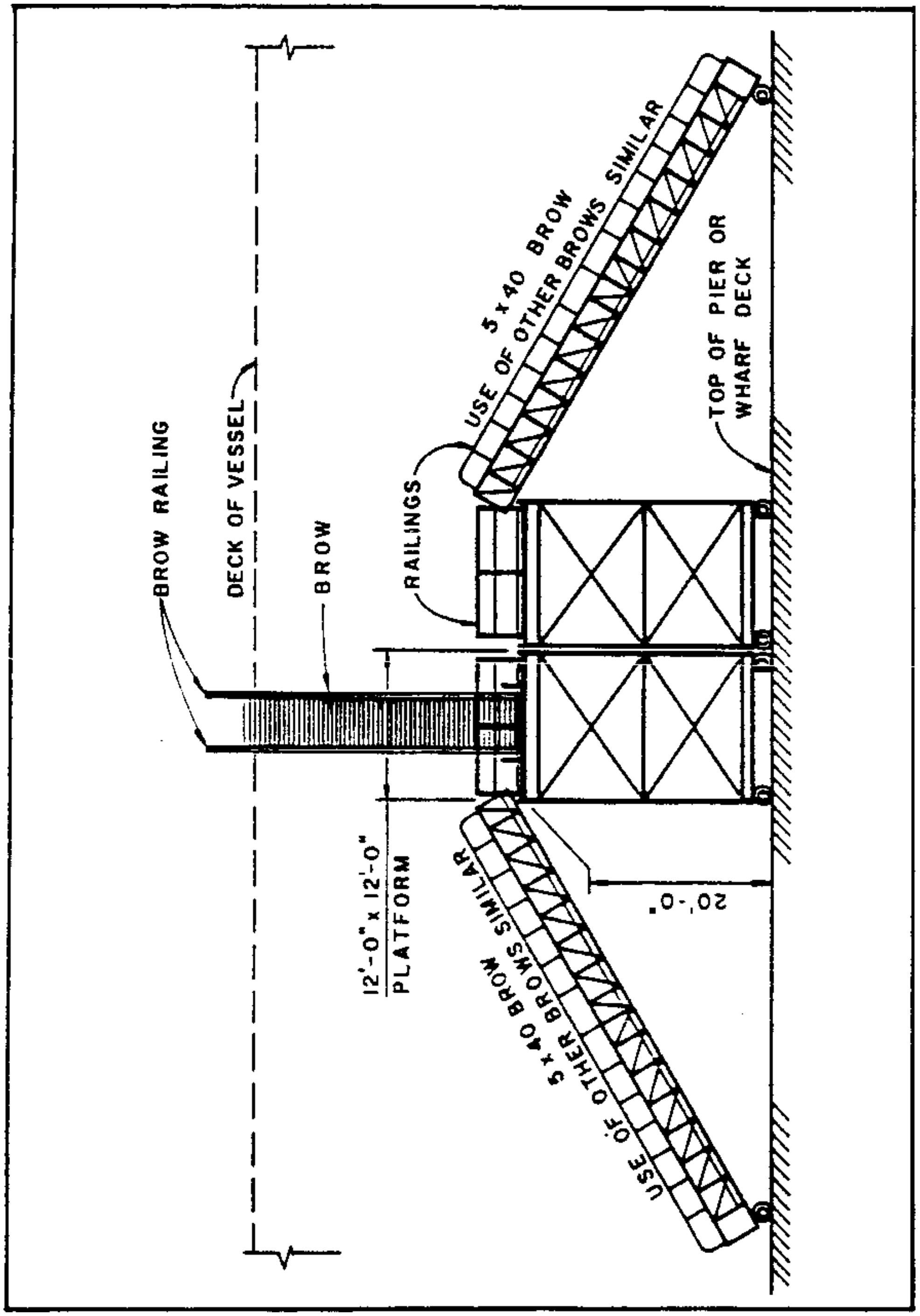

Figure 66
Brow Platform for Large Ships

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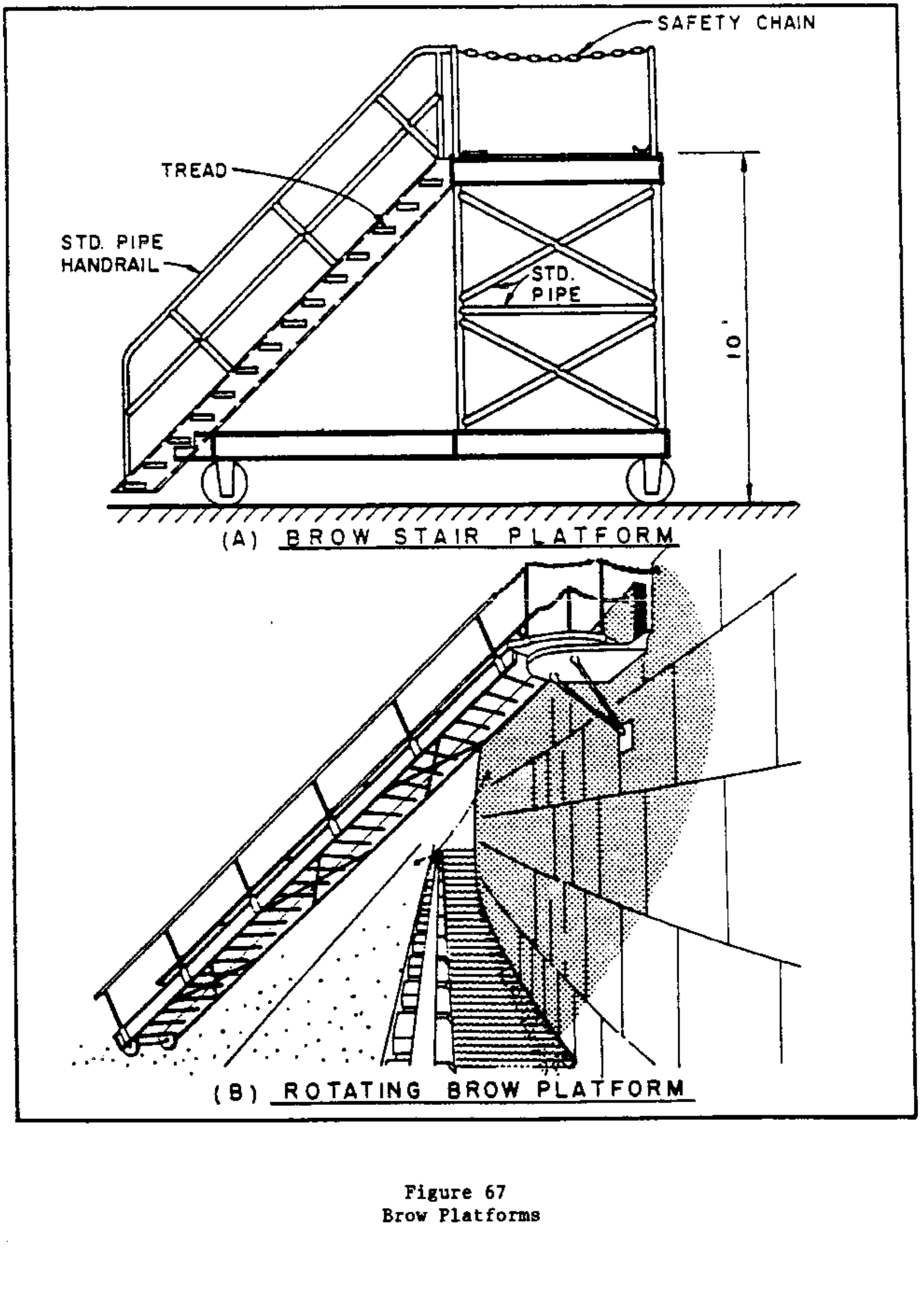

(A) BROW STAIR PLATFORM

(B) ROTATING BROW PLATFORM

Figure 67
Brow Platforms

7.6 Ramps. Transfer bridges or ramps are sometimes required for moving vehicles or heavy cargo from ships, similar to a roll-on/roll-off (RO/RO) operation. MSC RO/RO ships do not require any special features on existing Navy piers. Sideport ramps are stowed and handled by the ship. Sternport ramps are hinged to the vessel and extend to dockside or floating equipment (lighters, causeways, stages). These ships also have conventional cargo gear. The LHA-class of amphibious assault ships, having vertical lift stern gates, possess RO/RO capability. Installations accommodating vessels of this type should consider the use of a ramp or transfer bridge, as shown on Figure 68, to minimize the time required for movement of vehicular equipment and for loading of supplies. Design and construction of ramps should be similar to highway bridges.

7.7 Utility Booms. These are basically cantilevered arms used to support electrical cables in submarine berths. See Figure 69. The boom should be supported by the pier or wharf structure as close to the bullrail as possible for efficient operation. The boom is usually swung parallel to the bullrail for stowing. The material for boom construction is usually steel. Design of the boom structure should be according to NAVFAC DM-2.03, Structural Engineering - Steel Structures. For mechanical requirements, refer to NAVFAC DM-38.01, Weight Handling Equipment.

7.8 Fuel Loading Arm. At fueling piers and wharves, loading arms (as shown in Figure 70) are used at dedicated positions for efficient transfer of fuel. Design and construction requirements of loading arms are similar to utility booms.

7.9 Access Ladders and Life Rings. Ladder access from pier or wharf deck to waters should be provided at a maximum spacing of 400 ft on centers or within 200 feet of the work area ~~unless a closer spacing is required by local OSHA requirements~~ per 29 CFR 1917.26(f). Such ladders should be at least 1 ft 4 in. wide and should reach the lowest water elevation anticipated. Safety cages are not required. The ladder should be located on either side for a pier (50 ft or more wide) and on the water side for a wharf at places convenient to anyone who might accidentally fall into the water. Also, 29 CFR 1917.26 requires that a U.S.Coast Guard approved 30 inch life ring with at least 90 feet of line attached be available at readily accessible points at each waterside work area where the employee’s work exposes them to the hazard of drowning. Interpret as one life ring per wharf.

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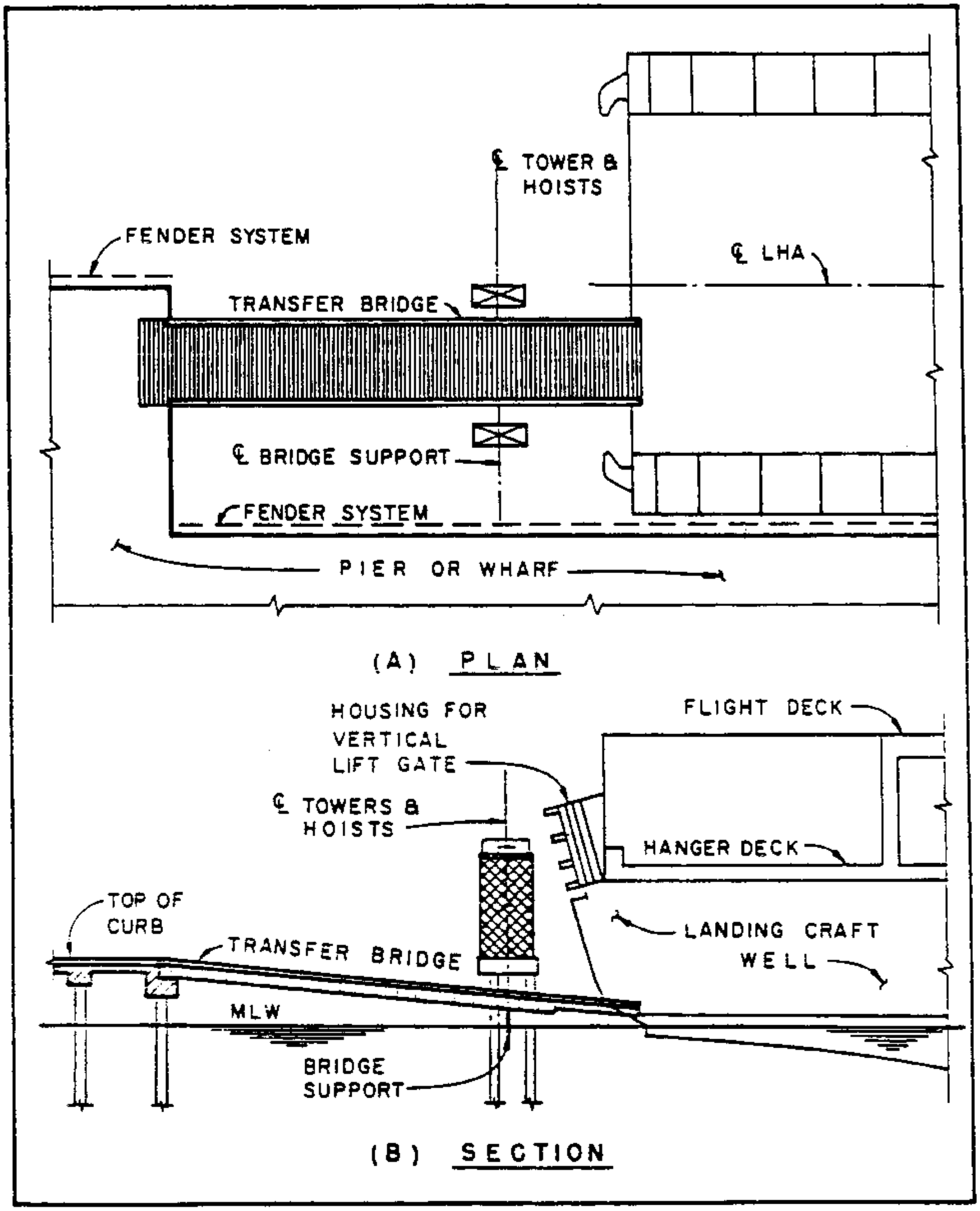

Figure 68
Transfer Bridge for LHAs

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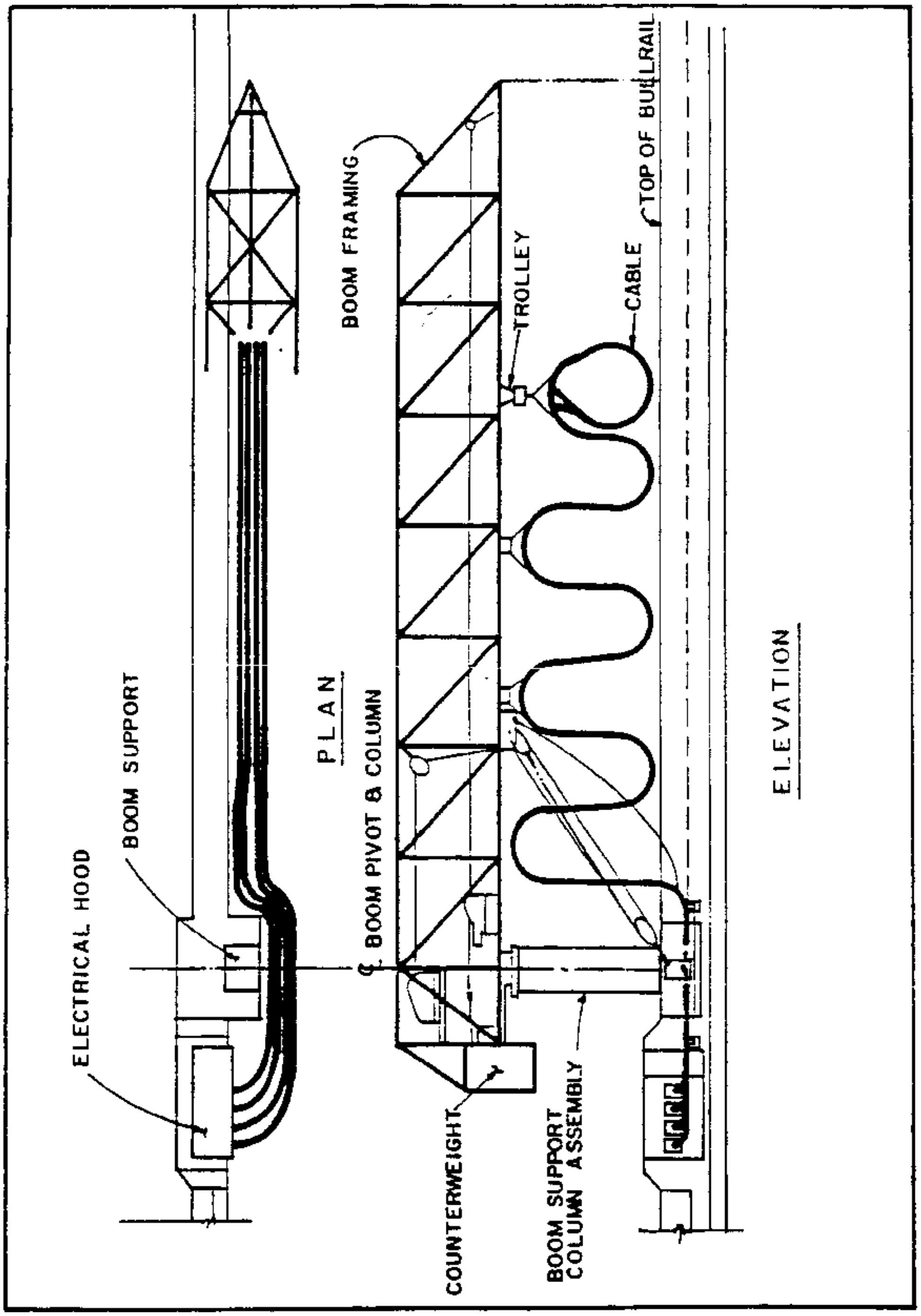

Figure 69
Utility Boom for Submarines

ADD DETAIL OF BOOM SIMILAR TO THOSE PROVIDED ON WHARF Y-3, PEARL HARBOR AND REFERENCED IN THE P.O.E. OF SEPTEMBER 1995

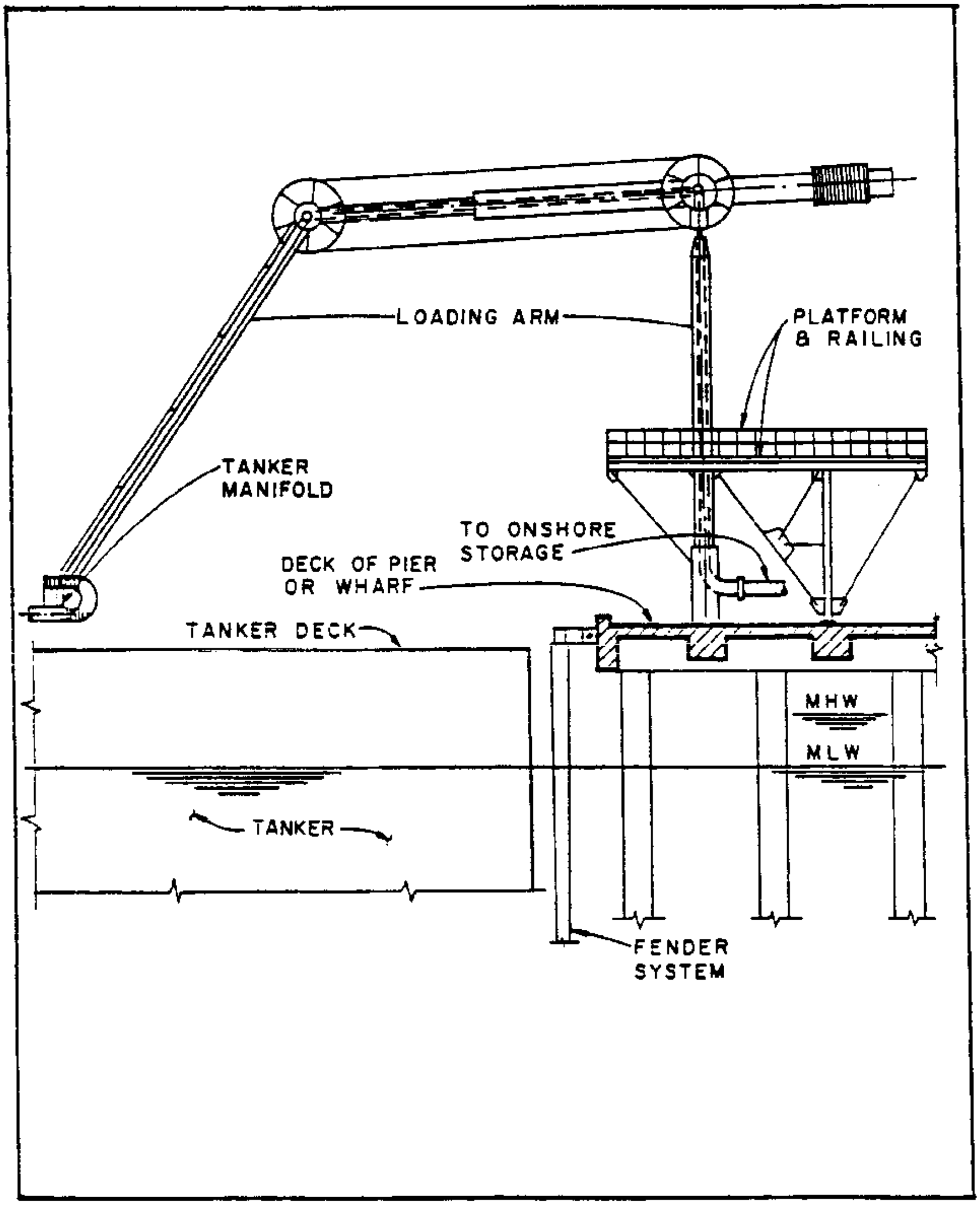

Figure 70
Fuel Loading Arm

APPENDIX A
FACILITY PLATES

The following facility plates have been included in MIL-HDBK-1025/1 for the purpose of presenting an overview of some typical naval waterfront facilities. The plates have been developed from drawings of existing facilities and illustrate the nature and interrelationships of the different elements. However, the details shown in the plates may be inconsistent with the text presented in MIL-HDBK-1025/1 and other referenced design manuals. In all situations, the criteria and recommendations of the design manuals should govern.

188

Small Craft Berthing	155-20	2a

189

Small Craft Berthing	155-20	2b

190

Small Craft Berthing	155-20	2c

191